# THE FACE OF THE EARTH

## (DAS ANTLITZ DER ERDE)


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# PREFACE BY THE AUTHOR

Dear Professor Sollas,

I am extremely gratified by the news that the Clarendon Press intends to do me the honour of issuing an English edition of my book *Das Antlitz der Erde*, and that this is to appear under an *aegis* so distinguished as yours. The honour is so much the greater since the first volume had already appeared in 1885, the second in 1888, and the first half of the third in 1901. With the lapse of time so much has been accomplished in the exploration of distant regions, as well as in the more detailed study of countries already known to us, that the reader will meet here and there in the first two volumes with a description already antiquated. In a comprehensive work, however, which is devoted not to the formulation of laws, but to the comparison of observations scattered over the whole earth, and the endeavour to establish connexion and correspondence between them, deficiencies of this kind can never be entirely avoided, certainly not when the advance of knowledge is so rapid as at present. A criticism of previous views must in addition be the natural result of this method.

Now, however, you must permit me to say a little more concerning myself than would under other circumstances be consistent with the laws of modesty.

In the year 1849 my geological investigations began in the Archaean and Silurian districts of Bohemia; in 1850 I proceeded to the Alps; and in 1851 I was commissioned to make a section across the Dachstein mountains, one of the lofty masses of Trias limestone in the eastern Alps. The contrast to Bohemia, with its vast rounded masses of gneiss and horizontal sheets of Quader sandstone, was particularly striking. In 1854 I became acquainted in Switzerland with Bernhard Studer, and Arnold Escher von der Linth. Escher with all his simplicity was a remarkable man. He was one of those possessed of the penetrating eye, which is able to distinguish with precision, amidst all the variety

of a mountain landscape, the main lines of its structure. He had just come forward with the magnificent conception, unheard of in the views of that time, of a double folding of certain parts of the Alps, which has since received the name of the 'double fold of Glarus.' Studer opposed him. Such movements of the mountains were, he said, contrary to nature and inexplicable. Escher did not concern himself with the explanation, but with the facts.

A few years later I had the good fortune to make the acquaintance of Sir Charles Lyell, with whom, as with Escher, I maintained friendly relations till the close of his life. On the one side stood Sir Charles, the calm superior philosopher, the lucid thinker and clear writer; on the other dear old Arnold Escher, who entrusted his admirable sketches and diaries to every one indiscriminately, but to whom every line he had to publish was a torment, and who was perhaps only quite in his element up in the snow and ice, when the wind swept his grey head and his eye roamed over a sea of peaks. In characterizing this time I only mention these two important men, because in the contrast of their qualities the whole wide field of activity in our glorious science is brought into view. Lyell's *Principles*, however, of which the ninth edition appeared in 1853, while investigating at length many fundamental questions, scarcely touched that of mountain-formation: Escher would not enter at all into the discussion of theoretical questions.

In 1852 Élie de Beaumont's 'Notice sur les systèmes des montagnes' appeared in a form not very easily accessible, the *Dictionnaire universel d'histoire naturelle*. The geometrical theories put forward found little appreciation outside France; apart from these, however, the treatise contained many new and suggestive views on the origin of mountains. Nevertheless the idea of the dependence of the more recent on the older folding found no expression in it, and when I thought of the contrast between Bohemia and the Alps one of the few beacon-lights appeared to me to be the profound words of Sir Henry de la Bêche published in the year 1846 in the first volume of the *Memoirs of the Geological Survey of Great Britain*, p. 221: '*that the foldings of the mountains of South Wales correspond to adaptation to a complicated lateral pressure.*'

Let me now review rapidly the subsequent *decennia* in which

geological opinions underwent step by step a profound change. They were modified in England as elsewhere. I have observed with great pleasure that as early as 1873 you yourself put forward in a Syllabus of a Course of Lectures on Geology the two principles that earthquakes may proceed from tectonic processes, and that the buttress of earlier Palaeozoic land may have had considerable influence in determining the direction of the folds in South Wales.

The theory of elevation craters fell to the ground. 'What,' it was asked, 'is really meant by elevation?' The classical examples, the temple of Serapis and the Baltic sea, even presupposing the complete correctness of the facts, illustrated only locally limited processes, and it was not possible to explain by them the undeniable fact that the terminology of formations, created in England, might be applied over the whole globe. Some universally active causes must exist. The formation of mountains, however, evidently belongs to quite another series of phenomena, and the horizontal strand-lines which may be observed above the existing sea-level are quite independent of the anticlinals and synclinals of the slope along which they extend.

If we consider one of the most regularly built and most exactly known of mountain ranges, the Jura, we shall find nothing that would correspond to a central axis of elevation in the older sense of the term. The dependence of the processes of mountain-formation on older elements which check and oppose, on lateral pressure and deflexion, become daily more evident, as for instance in the thrusting of the north-west of Scotland over the gneiss of the Hebrides. Thus our very first consideration of existing observations brings us back to the felicitous expression of accommodation to lateral pressure. Now we understand why the Alps extend towards the Carpathians in a concave curve, avoiding the older Bohemian mass, and we are led to a comparison of the mutual relations between the great structural units.

Even in 1885 and 1888, the dates at which the first volumes of this work appeared, the possibility was recognized of deducing from the uniform strike of the folds of a mountain-chain a mean general direction or trend-line; such trend-lines were seen to be seldom straight, but as a rule arcs or curves, often violently bent curves of accommodation; the trend-lines of central Europe were

observed to possess a certain regular arrangement and to be traceable in part as far as Asia. It was further recognized that the ocean from the mouth of the Ganges to Alaska and cape Horn is bordered by folded chains, while in the other hemisphere this is not the case, so that a Pacific and Atlantic type may be distinguished; that the Mediterranean is not part of the Atlantic Ocean, but the remains of a sea which once crossed the existing continent of Asia, and has since been enlarged by subsidence: that at various times, as for instance during the middle and upper Cretaceous period, an extension of the seas occurred much too general and too equable to be explained by the subsidence of continental land, and so on. All these results completely crushed the hope of arriving at a geometrical plan of the face of the earth, but the desire to discover whether some plan of another kind might not determine the distribution of mountain ranges received a fresh impulse. In 1888, however, it was not possible to further pursue this path. Important English investigations had been published on the Himálaya; Java was known; Richthofen had explored China; Japan was becoming accessible. The results of all these important researches, however, and the map of the curves formed by the islands of eastern Asia show a number of peripheral, chiefly arc-shaped fragments surrounding a vast and wholly unknown centre situated in Mongolia and Siberia, the exploration of which could alone furnish continuity.

The third volume had already advanced far towards completion within the limits originally proposed when an examination of these very regions was commenced on a large scale preparatory to the construction of the Siberian Railway. At the same time a number of distinguished geologists combined in Paris under the direction of MM. Marcel Bertrand and Emile de Margerie with a view to publishing a French edition of the *Antlitz*, and this flattering circumstance strengthened me in the resolve to extend my task before its conclusion. Meanwhile Teleki and Höhnel had discovered lake Rudolf in Africa, and with it the Ethiopian rift valley; Széchény and Loczy, Obrutschew and others had explored central Asia and enabled us to bring the trend-lines of Burma into connexion with those of the great ranges of the interior; the united efforts of French and Swiss geologists in the western Alps led to

conceptions which went much further than Escher's double fold, received with so much incredulity at the time; Törnebohm pointed to lateral movements in Scandinavia of no less importance; through the devotion and insight of our American colleagues the remarkable structure of Alaska became increasingly clear. From all sides came fresh information.

The first half of the third volume is thus mainly devoted to Siberia and the relations of the inner Asiatic trend-lines. The second half will contain the conclusion of the descriptive part, and some chapters of synthetic matter which refer to the whole planet. In this a plan of the trend-lines of the earth will be found. It will be a first attempt, burdened by all the difficulties, perhaps too all the errors, arising from this circumstance, but it will have fully accomplished its purpose if it is found fit to serve as a link to the fresh observations which unceasingly succeed one another.

I remain, esteemed colleague,

Yours very sincerely,

E. SUESS.

VIENNA: *January*, 1904.

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# INTRODUCTION

Wedge-like form of the continents. Great depth of the oceans. Difference between the Pacific and Atlantic regions. Subsidence. 'What is a geological formation?' Cycles of development. The stratigraphical terminology of Europe applicable to the whole world. Extent of transgressions. Independence of ancient coast-lines and mountain-structure. Contents of the following parts.

If we imagine an observer to approach our planet from outer space, and, pushing aside the belts of red-brown clouds which obscure our atmosphere, to gaze for a whole day on the surface of the earth as it rotates beneath him, the feature beyond all others most likely to arrest his attention would be the wedge-like outlines of the continents as they narrow away to the South.

This is indeed the most striking character presented by our map of the world, and has been so regarded ever since the chief features of our planet have become known to us. It recurs in the most diverse latitudes: Cape Horn, the Cape of Good Hope, Cape Comorin in the East Indies, Cape Farewell in Greenland are some of the best known examples.

Attempts have been made to explain this form by the alleged existence of an excessive accumulation of water towards the South Pole: but these promontories do not slope gradually into the sea, on the contrary they are rocky, and their declivities as a rule descend abruptly to great depths. An equal accumulation of water about the North Pole would not give rise to analogous outlines.

Such forms must consequently have been determined by the structure of the outer parts of the planet itself.

Our observer would have no doubt on this point, if, as he had previously pushed aside the clouds, he were now to remove the sea, so that he could gaze directly on the rocky crust of the globe thus laid bare. The remarkable depth of the ocean basins as opposed to the trifling height of the continents, and the steep slope of a great part of the coasts, would then become apparent to him.

Long ago Alexander von Humboldt aptly compared the continents to 'plateaux' rising out of the ocean depths.

Carpenter estimates the mean height of the continents in round numbers at 1,000 feet at most, the mean depth of the oceans at 13,000 feet[1].

Krümmel, following Leipoldt, calculates the average elevation of the continents at 440 meters, the average depth of the oceans at 3,438·4 meters

[1] W. B. Carpenter, Land and Sea, considered in relation to geological Time; lecture Roy. Inst. Gr. Brit., Jan. 23, 1880, p. 4.

(1,880 fathoms). If all the inequalities of relief were reduced to a mean level the whole surface of the planet would, according to Krümmel's data, be covered with water to the depth of 1·5625 miles (2·52 kilometers or 1,375 fathoms)[1].

The mean value of existing inequalities, obtained by adding the mean height of the continents and the mean depth of the oceans, will be, according to Carpenter, 14,000 feet (4,267 meters), or, according to Krümmel, 3,878·4 meters. But our observer of the exposed globe would perceive a more marked contrast in relief than these figures indicate, for they have been determined without taking into consideration a circumstance which masks to a great extent the steepness of the coasts and the contrast between land and sea, namely, the attraction which the continents exert upon the mass of the ocean.

It is usually assumed that the surface of the ocean is everywhere of equal elevation, that is to say, that every part of it, and consequently every part of its coast-line, is equally distant from the centre of the earth. But this assumption, although a great deal of our geodetic work is based upon it, cannot be maintained. Since the earlier investigations of Saigey and Stokes, and particularly since the more recent researches of Fischer, and the lucid exposition of the facts which we owe to Hann, it must be considered as proved that the mass of the continents exerts a considerable attraction upon the ocean and that consequently the surface of the sea rises towards the mainland[2]. If we were to make a section across one of the great oceans in the plane of a parallel of latitude, we should see that, at the middle of the ocean, the surface lies nearer the centre of the earth than the coast-line on either side. The difference of elevation in meters amounts, according to Fischer, to about 122 times the difference of the number of oscillations of the pendulum in twenty-four hours. This would give, with a difference of nine oscillations, for example, between an oceanic island and the coast, an actual difference in elevation of about 1,100 meters, or 3,609 feet. The shores of the continents, and the continents themselves, consequently appear much lower to the eye than is actually the case; the attraction of the sea to the land conceals to a great extent the contrast which really exists between continent and ocean[3].

[1] O. Krümmel, Versuch einer vergl. Morphologie der Meeresräume, 8vo, Leipzig, 1879, pp. 102, 106, 107.

[2] Fischer, Untersuchungen über die Gestalt der Erde, 8vo, 1868; Hann, Ueber gewisse beträchtliche Unregelmässigkeiten des Meeresniveau's, Mitth. Geogr. Ges. Wien, 1875, VIII, pp. 554-569.

[3] Listing attempted to determine the effect of the attraction in a large number of places and found: London, 118 meters; Paris, 268 m.; Island of Marañon (N. Brazil coast), 567 m.; Bonin Island, - 1,309 m.; St. Helena, - 847 m.; Spitzbergen, - 217 m.; Berlin, 37·7 m.; Königsberg, 92·6 m.; cf. Listing, Neue geometr. und dynam. Constanten des Erdkörpers, Nachrichten d. k. Gesellsch. d. Wiss. zu Göttingen, 1877, pp. 749–815.

The significance of this fact becomes apparent if we suppose the attraction to cease. That portion of the ocean which is now drawn up over the margin of the continents would subside, many of the bays which deeply indent the continents would be laid completely dry; the continents would gain somewhat in extent, and a great deal in height and continuity. But while the continents would gain in prominence, the ocean would gain in depth, and the uniform distribution of that portion of the ocean formerly held bound by the continents would perhaps lead to the submergence of a number of low oceanic islands.

Soundings made from the coast to the open sea apply therefore not to a horizontal, but to a concave surface; this circumstance makes an essential difference in the profile of the sea bottom.

Carpenter, as we have said, estimates the mean height of the continents at 1,000 feet at most, Krümmel at 440 meters; the example taken to show the influence of attraction gave 1,100 meters for the rise of the ocean, that is to say, more than twice, indeed nearly three times, the higher estimate for the mean height of the continents. Even supposing these figures to be exceptional, and the mean result of attraction to sink to less than one-half the figure quoted (a point on which I lack means of forming an opinion), there still remains ground for a comprehensive correction of prevailing views.

If we further wish to determine the vertical distance between the line of mean elevation of the continents and the line of mean depression of the ocean, that is to say, the mean value of the difference in relief, it is not sufficient to add together Krümmel's two figures (440 + 3,438·4 = 3,878·4 meters) as has been done above. Another figure must be added for the force of attraction, which will increase this sum considerably, certainly to far above 4,000 meters. This would be the mean value of the inequalities which would present themselves to the eye of our observer.

A number of the most difficult questions thus confront us on our first consideration of the main features of the earth's surface.

How can we account for these great abysses of the ocean?

Under the impression produced by their extraordinary magnitude, and under the conviction that the older notions as to the rise and fall of the land are by no means sufficient to account for such startling and extensive differences in relief, an opinion has taken root that the changes so often cited as having occurred in the distribution of land and sea are after all only demonstrable, and indeed conceivable, within somewhat narrow limits; and that the position of the great continents and ocean basins has remained essentially unaltered since their first existence[1].

[1] L. Agassiz, Report upon Deep-Sea Dredgings, Bull. Mus. Comp. Zool. Harvard Coll., Cambridge, Mass., 3rd ser., 1869, p. 368; Dana, Am. Journ. Sc. Arts, 1873, 3rd ser., VI, p. 169; Geikie, On Geographical Evolution, Proc. Roy. Geogr. Soc., 1879, new ser., I, pp. 422, 443.

It might indeed appear as though the submersion of our existing continents in past times, that is, since the completion of the lower Silurian period, had hardly extended further than to a comparatively small fraction of the mean depth of the existing ocean. Murray has shown in a most thorough and convincing manner that the deposits now forming at great depths in the ocean are exclusively of organic, volcanic, or meteoric origin. They are completely free from any admixture of mineral matter derived from the surface of the land, and are thus distinguished from the immense mass of marine deposits, which are to be met with in our mountains and plains, and which find their nearest equivalents in sediments now accumulating at comparatively slight distances from the land, and at moderate depths of the sea [1].

The frequent intercalation of fresh-water deposits during later periods, as well as the concomitant replacement of one terrestrial fauna by another—a fact which so clearly demonstrates the continuity of life on the dry land—may be regarded as confirming this opinion with regard to the later periods of terrestrial history.

On the other hand, the thickness of the marine deposits which contribute to the formation of the continents is at times so extraordinarily great, that it is difficult to account for the absence of abyssal characters; and not only is the manner in which such considerable masses of sediment are incorporated with the continents an unsolved problem, but also the question as to the position of those other continents, by the demolition of which these vast masses were produced.

It is sufficient to recall the thousands of feet of Triassic and Rhaetic limestone in the Alps, and the thickness of the much younger Flysch, not to mention the great development of Palaeozoic deposits in England. In Central Pennsylvania, according to measurements of a transverse section made by Ashburton, the total thickness of deposits from the summit of the *Alleghany River Coal Series* to the Trenton limestone (neglecting, that is, the lower part of the Silurian) amounts to 18,394 feet [2].

It would not be difficult to cite a large number of regions where the total thickness of the marine deposits is as great as the approximate mean depth of the sea at the present day, that is, from 4,000 to 5,000 meters. How great then, on prevailing assumptions, must the subsidence of a district once have been, where not merely the depth of the ocean covering it, but even the thickness of sediment deposited have attained so great a magnitude!

The extremely important part which Palaeozoic deposits play in the formation of continents, as for instance in China, is an irrefutable testi-

[1] Murray, On the Distribution of Volcanic Débris over the Floor of the Ocean; Proc. Roy. Soc., Edinb., 1877, IX, pp. 247-261, and elsewhere.

[2] C. A. Ashburton, A measured Section of the Palaeozoic Rocks of Central Pennsylvania; Proc. Am. Phil. Soc., Philadelphia, 1877, XVI, pp. 519-560.

mony to the vastness of the change which has taken place. The high pedestals on which our continents rest may therefore be very ancient, they may even date, in great part, from the Mesozoic period; but for the Palaeozoic period it would be impossible to maintain the theory of generally persistent continents; and that part of the borders of continents which cuts across the strike of younger mountain ranges is certainly of quite recent date.

In considering, therefore, the wedge-like form of the continents, we are not dealing with something which has remained unaltered since the formation of the globe; still, in any attempt to understand the movements of the earth's crust and its changes of form, this most important feature of the planetary surface must be taken into account.—

Let us now further suppose that our imaginary observer has approached so near to the earth, that he can perceive not only the outlines and the relief of the continents, but also the relations existing between their outlines and the mountain ranges they support. Then he will perceive that two regions may be distinguished on the planet, marked by a difference in the relations of the boundaries of the ocean basins to the mountain chains of the continents.

From Chittagong, at the head of the Bay of Bengal, down to Java, and along the Asiatic coast of the Pacific Ocean, through Japan and the Kuriles, and then eastwards through the Aleutian islands to Alaska, there occur on the mainland itself, or on the long rows of bordering islands, more or less continuous lines of mountain chains, the course of which runs either parallel to the coast or in curves concave to it, so that the islands surround the mainland like so many pendent festoons; thus showing that some definite connexion unquestionably exists between the outer delimitation of the continent and its internal structure.

Equally obvious is the relationship between the direction of the coast-line and the course of the mountain chains on the west coast of North America, as far as California, and throughout the whole of South America.

From the Ganges to Cape Horn a correlation of this kind is the rule; it is the distinctive character of the *Pacific Type.*

If we turn now to the east side of Cape Horn we find the case entirely changed. The mountains strike towards Staten Island, and Cape Horn itself follows the Pacific rule. But to the coast of Patagonia and Brazil, and indeed the whole eastern side of America as far as Greenland, with the exception of the region of the Antilles, this rule does not apply. Where a mountain range does occur in close proximity to the sea, as for example in the case of the Appalachian mountains, it turns its back to the sea; no causal connexion whatever is perceptible between the coast-line and the structure of the continent. This is the case along the whole of the west

coast of the Old World, with the exception of a part of the western Pyrenees.

Scotland, Brittany, and Portugal afford striking examples of coast-lines which cut transversely across the structure of the land. In the north of Scotland we see with unusual distinctness how the great faults trending to the north-east, which traverse the whole country, run out against the sea, while the dislocation of the land between them has indented the shore in zigzag form[1].

This absence of connexion between the course of the sea-coast and that of the mountain chains is characteristic of the *Atlantic* region.

Thus the existing outlines of the aqueous envelope of the planet coincide, in by far the larger part of the Pacific region, with easily recognizable features in the structure of the globe, while in the Atlantic region no such correspondence is to be observed. But as soon as we attempt to apply this distinction to the Indian Ocean we perceive that while the whole of the east coast of Africa, the Arabian coast, and that of the Indian Peninsula as far as the Ganges conform to the Atlantic type, and that the same is true of the Australian coasts far to the south-west, yet that between these, from Chittagong to beyond Java, the Pacific type, as already mentioned, makes its appearance. The boundary of the two regions is to be sought on the mainland. It runs from the plains of Bengal, along the outer chains of the Himalayas, to the north-west, then from the Punjab to the mouths of the Indus, then along the Persian Gulf and the lower course of the Euphrates, and is continued, as we shall see later, under most complicated conditions, from the Gulf of Gabes through Morocco to the Atlantic coast of Africa. In this manner the three great southern masses of Africa, India, and Australia, which follow the Atlantic type, are separated from the north.

The mightiest mountain chains of the earth are themselves only subordinate members of far greater structural features which dominate the whole globe. We may observe and describe in detail the disposition of the strata and the structure of any single mountain chain we please, but it will be found impossible to give an explanation of the facts it presents without taking into account the relations which exist between this particular chain and the assemblage of mountain chains in general.—

Let us now place our observer on the green sod of our earth, that he may more closely observe the relations of the strata in the various mountain chains. He wanders over hill and vale, but sees scant traces of the mighty movements which have affected so many parts of the earth's surface. The ridges are worn away by wind and weather, the low ground covered with mud and sand. Great mountain ranges are reduced to hilly

[1] Judd, The Secondary Rocks of Scotland, I; Quart. Journ. Geol. Soc., 1873, XXIX, p. 130, and pl. vii, map of Moray Firth.

land or even to plains; the fractures, along which displacements of mountain segments have taken place to the extent of thousands of feet, are so completely concealed from the eye that they have only become known at all by means of subterranean workings.

The fault in the tunnel of Fuveau near Marseilles, which has a throw of about 1,200 meters, and brings the Muschelkalk into contact with much younger strata, was not even suspected at the surface of the ground [1].

The brothers Rogers infer subsidences of strata in the coalfields of Virginia to the extent of 7,000–8,000 feet [2], and in the same district the west side of the anticlinal 'Cove Canoe' is, according to Lesley, traversed by a fault twenty miles in length, with a throw of at least 20,000 feet [3].

We have only, however, to try to picture to ourselves any district, the structure of which is fairly well known, suppressing in thought the results of denudation, and we shall often enough see mountain ranges rise to heights which (though they may indeed never have been actually attained, since denudation probably progressed simultaneously with elevation) yet nevertheless afford us a true measure of the vertical movements which have taken place. Let us imagine the whole Palaeozoic mantle of Saxony, which at present terminates in a fold at the northern border of the Erzgebirge, to be continued on to the heights of this mountain range, in place of the little patches of Rothliegende and Cretaceous, which reveal the great antiquity of the denudation; or let us extend over the older rocks of our Alps only a part even of the Mesozoic formations which form their lateral zones, and how completely the aspect of our mountains is transformed! In this way Clarence King, prolonging the Palaeozoic strata from the east to the crest of the fracture, along which, on the Great Salt Lake, the western part of the Wahsatch mountains is thrown down, estimates the amount of this throw as at least 30,000 feet, or even 40,000 if the Cretaceous formation be taken into account [4]. In this consists the great interest of the stereogram of the Uinta mountains constructed by Powell at Gilbert's suggestion, by which the true proportions of the subsidence make a direct appeal to the eye [5].

We shall, however, have occasion to show that the crust of the earth is traversed not only by isolated faults of this kind, but by whole systems of fractures, that extensive areas have thus been broken up and have foundered into the interior of the planet.—

[1] Dieulafait, Comptes rend., 1879, t. 88, p. 351.

[2] H. D. Rogers, The Geol. of Pennsylvania, 4to, Philad., 1858, vol. ii b, p. 897.

[3] Dana, Manual of Geol., 3rd ed., p. 399.

[4] Clarence King, U. S. Explor. Exped. of the 40th Parall., 4to, 1878, I, p. 44; Emmons, op. cit. II, p. 340.

[5] J. W. Powell, Report on the Geol. of the Eastern portion of the Uinta Mount., 4to, 1876, p. 175, Atl. pl. iii.

We will now turn our attention from phenomena of this kind and lead our observer down from the mountains into our schools. He has already taken count, under the panoply of clouds, of the wedge-shaped outlines of our continents, then, beneath the sea, has perceived the great depth of the ocean basins; he has recognized the difference between the Pacific and Atlantic coasts, and finally the thoroughgoing concealment of great fractures. The wanderer shall now become a listener. The leading features of this noble branch of science, the history of the earth, shall be expounded to him. He hears of the wonderful extension of human knowledge attained by examining the spectra of the celestial bodies, then of the various phases of cooling in which these bodies exist at the present day, of the conclusions which may thence be drawn concerning the formation of our solar system, and concerning that long and earliest period in the existence of our planet, during which the conditions necessary for organic life were not yet present; then he hears how later water, air, and life successively made their appearance, and how the period succeeding to these events is divided into geological formations, into aeras, periods, and stages.

Supposing our listener to have now reached this point, so that he stands on the threshold of stratigraphical geology, and at the same time of the history of life: he will find himself surrounded by an overwhelming mass of details concerning the distribution, stratification, lithological character, technical utility, and organic remains of each subdivision of the stratified series. He stops to ask the question: what is a geological formation? What conditions determine its beginning and its end? How is it to be explained that the very earliest of them all, the Silurian formation, recurs in parts of the earth so widely removed from one another—from Lake Ladoga to the Argentine Andes, and from Arctic America to Australia—always attended by such characteristic features, and how does it happen that particular horizons of various ages may be compared to or distinguished from other horizons over such large areas, that in fact these stratigraphical subdivisions extend over the whole globe?

This question is certainly obvious and justifiable, but if we could assemble in one brilliant tribunal the most famous masters of our science, and could lay this question of the student before them, I doubt whether the reply would be unanimous, I do not even know if it would be definite. Certain it is that in the course of the last few decades the answer would not always have been the same.

Let us glance over the period from 1849 to 1859. The doctrine of successive creations reigns everywhere. Each larger subdivision of the geological series is considered to denote an act of special creation. At the same time wide divergences of opinion exist as to the causes which lead to the extinction of a fauna. In Belgium and France this question is eagerly

discussed. Most commonly the elevation of mountain chains is assumed as the cause of these cataclysms, and an attempt is made to establish a correspondence between the results of Palaeontology and the attempts of Élie de Beaumont to prove that the distribution of mountain chains in time and space is subject to a geometrical law.

Dumont maintains, in opposition to Koninck, that the present zonal distribution of climates has always existed, that faunas such as those of the Silurian, Devonian, and Carboniferous formations might easily have lived at the same time, but in different latitudes, and have gradually advanced one after the other from the Poles to the Equator. At the same time Dumont by no means denies the correctness and value of the views of Élie de Beaumont; he takes into consideration, however, besides the supposed rapid elevation of mountain ranges, the slow movement of the earth's crust, the advance or retreat of certain deposits over large areas, and makes use of these phenomena to determine the subdivisions of the Tertiary formation. One might say that Dumont endeavours to give prominence to the transgressions as well as the discordances [1].

Barrande seeks to determine to what extent the elevation of mountains is to be regarded as a local phenomenon; but he adheres to Beaumont's statement, that every mountain system may extend over an arc, lying between two great circles making between them an angle of twenty degrees at the Equator, and expects further results from a comparison of the chronological table furnished by Palaeontology with the chronology of discordances [2].

Not long after d'Archiac asserts positively the complete ineffectiveness of great dislocations of the earth's crust upon the law which determines the succession of life [3], and in 1859 Hébert proves that the fresh-water deposits, which separate the Jurassic and Cretaceous formations, extend from the Jura mountains to Hanover and England, and concludes from this fact the dependence of these alternations on the oscillation of considerable areas, but not on the local elevation of mountains [4].

While in France the older theory of the repeated and sudden destruction of all organisms falls more and more into disrepute, in England Edward Forbes has already shown how elements of different age may be distinguished within the present population of Europe [5], and in North Germany,

[1] A. Dumont, Note sur l'emploi des caractères géométriques résultant des mouvements lents du sol, pour établir le synchronisme des formations géologiques; Bull. Acad. Roy. Belg., 1852, XIX b, pp. 514–518.

[2] Barrande, Observations sur les rapports de la stratigraphie et de la paléontologie; Bull. Soc. Géol. de Fr., 1854, 2e sér., XI, pp. 311–326.

[3] D'Archiac, Histoire des progrès de la géologie, 1857, VII, Terr. jurass., p. 599: 'l'innocuité complète, si l'on peut s'exprimer ainsi. . . .'

[4] Hébert, Observations sur les phénomènes qui se sont passés à la séparation des périodes géologiques; Bull. Soc. Géol. de Fr., 1859, 2e sér., XVI, pp. 596–605.

[5] Edward Forbes, On the Connexion between the Distribution of the existing Fauna

Beyrich, by means of a widely observed transgression, defines the limits of the Oligocene series of the Tertiary formation[1]. At the same time traces of an older theory, which originated with Brocchi, are still to be met with, according to which each single species has, like an individual, its appointed period of life, and there is no need to assume any exterior cause for its decline[2].

About the year 1859, the majority of investigators attributed the differences presented by successive sedimentary series and by their faunas to the influence of slow and extensive oscillations of the continents, and to repeated changes of climate, perhaps connected with these oscillations.

At this point Darwin's book on the Origin of Species made its appearance:

'But just in proportion as this process of extermination had acted on an enormous scale,' says the author, 'so must the number of intermediate varieties, which have formerly existed on the earth, be truly enormous. Why then is not every geological formation and every stratum full of such intermediate links? Geology assuredly does not reveal any such finely graduated organic chain, and this perhaps is the most obvious and gravest objection which can be urged against my theory. The explanation lies, as I believe, in the extreme imperfection of the geological record.'

In a later passage Darwin says:

'I believe that the world has recently felt one of these great cycles of change: and that on this view, combined with modification through natural selection, a multitude of facts in the present distribution both of the same and of allied forms of life can be explained[3].'

These words, although applying only to the geographical distribution of forms of life at the present day, contain nevertheless the important admission, that the development of life has been, according to Darwin, *uninterrupted, but by no means uniform*; nay, it almost appears as though the reader were to be introduced to a further problem, that of a great and as yet unknown rhythm in the evolution of living beings—a rhythm dependent on periodic changes in the inorganic environment.

Aristotle seems to be alluding to the same problem in the remarkable passage: 'The distribution of land and sea in certain regions is not

and Flora of the Brit. Isles and the Geol. Changes, &c.; Mem. Geol. Surv., vol. i. p. 340.

[1] Beyrich, Ueb. d. Zusammenhang d. norddeutsch. Tertiärbildungen; Abh. K. Akad. Wiss. Berlin, 1855, pp. 1–20, and map.

[2] Brocchi, Riflessioni sul perdimento delle specie, Conchol. foss. subapp., 1814, 1, pp. 219–240; cf. also H. v. Meyer, Nov. Act. Ac. Leop.-Carol., XVI. 2, p. 474; Zur Fauna von Oeningen, p. 48; C. Darwin, Journal of Researches, p. 212; R. Owen, Brit. Fossil Mammal., p. 270; Barrande, Parall. entre les dépôts silur. de Bohême et de Scand., p. 54.

[3] Darwin, On the Origin of Species, chap. ix, On the Imperfection of Geological Record; chap. xii, Geographical Distribution, at the end.

always the same, but that becomes sea which once was land, and that land which once was sea, and there is reason to believe *that this change takes place according to a definite system and at definite intervals of time*[1].'

More than forty years have passed since the publication of Darwin's book. Since then observations have multiplied; we are now able with much greater certainty to trace the genealogy of living beings among the relics of the past, as, for instance, of the Carnivores, the Solipedes, the Echinoids, and many other groups, and we are thus led to perceive that variation tends more or less constantly in the same direction, the result so far being the existing range of forms. At the same time we occasionally find that the vicarious relationship between two successive mammalian faunas of the Tertiary period may be quite as close as that which now obtains between two existing terrestrial faunas of contiguous areas.

The continuity of life is thus more and more clearly illustrated by the results of Palaeontology; yet the fact remains that we do not find species varying gradually within the limits of single families or genera, and at different times, but that whole groups, entire animal and vegetable populations, or, if I may so express myself, complete economic unities of Nature appear together, and together disappear. This is the more remarkable, as the transformations effected in the populations of the sea and in those of the land by no means invariably coincide: a fact which has been proved in the most convincing manner by a study of the various subdivisions of the Tertiary formation in the Vienna basin. From this we may conclude with certainty that the determining factors in this case have been changes in the external conditions of life.

It is true that the record is extremely incomplete. A certain proof of this lies in the local recurrence of some groups. The recurrence of certain species of Ammonites in the Jurassic system of Central Europe has already been made use of by Neumayr to determine, in their main outlines, the boundaries between the zoological provinces which existed during the several subdivisions of the Jurassic period[2]. Communications have from time to time been established between these provinces and again suppressed; yet not only may the synchronism of the subdivisions in one province and another be determined in many cases with certainty, in spite of subsidiary differences, but throughout the whole earth we see the well-known general type of the Jurassic formation succeeded by the equally well-known type of the Cretaceous; and from this we may conclude that changes must have occurred which have exerted an influence over an area still more extensive than that of these great provinces.

[1] Aristot., Meteor., XII.

[2] Neumayr, Ueber unvermittelt auftretende Cephalodentypen im Jura Mittel-Europa's; Jahrb. d. geol. Reichsanst., 1878, XXVIII, pp. 37–80.

On this fact depends the unity of stratigraphical terminology. The excellent work of English geologists in East Australia, the reports of the Geological Survey in India, the accounts of our explorers in China and in the Arctic regions, the voluminous publications presented to us by North America, as well as the works of German investigators on the Andes of South America, the descriptions of the Cape, and the scantier but most valuable accounts which we have received from the less easily accessible parts of Africa—all these works, when they wish to designate the more important parts of a stratified series, make unhesitating use of terms which were originally chosen to describe the classification of the deposits in a limited portion of Europe. When it is a question of marine deposits the geologist in New Zealand or Victoria knows as well as his colleague in North Russia or Spitzbergen whether he has Palaeozoic, Mesozoic, or still younger deposits before him, and expressions such as 'Carboniferous Limestone,' 'Jurassic,' 'Cretaceous' have now become naturalized in all parts of the world visited by geologists.

The greater part of this nomenclature originated in England, and has obtained general recognition in spite of the fact that certain vast marine deposits occur in Central Europe, the chronological equivalents of which in England bear an entirely different character, and are not immediately recognizable. Such are the Trias formations of the Eastern Alps, and the Tithonian series. At the same time Abich, in his works on Armenia, and Waagen and Griesbach in India, are making known to us marine faunas, by which the mighty gap occurring in Europe towards the close of the Palaeozoic period is being steadily filled up. But more careful consideration easily convinces us that it is not the completeness of the series of marine formations in South-east and Central England, but rather, so to speak, that mean frequency of gaps among them, which has facilitated the conception of natural groups, in a manner which would never have been suggested by other places where one marine deposit regularly follows another. In those districts, however, where the incompleteness of the series is particularly great, and where, for example, the encroachment of the Cenomanian is apparent, there is a most striking correspondence over large areas and in both hemispheres. It was this correspondence which led me long ago to suppose that the so-called secular elevations and depressions of continents are not sufficient to explain the more limited distribution of some and the wider distribution of other formations, a phenomenon of which the cause, though unknown, must be general [1].

In like manner E. v. Mojsisovics has since designated as one of the most remarkable phenomena known to us 'the precisely parallel development of the chief features of the two great continental masses of the Northern

[1] Die Entstehung der Alpen, 8vo, 1875, pp. 115–120.

hemisphere,' and the 'concordant cycle of dynamic transformations on both sides of the ocean [1].'

Some years earlier eminent American geologists, following quite another course of observation, thought that they recognized, within the stratified series of their continent, a certain periodic return of those conditions under which the deposition of sediments takes place. According to them every great formation begins with a deposit of clay or sand in shallow water, and is then followed by a calcareous marine deposit, whereupon the depth of the sea again diminishes.

These series were spoken of as 'cycles of deposition.'

Dawson has furnished a detailed account of the four cycles for lower Silurian, upper Silurian, Devonian, and Carboniferous [2], and Newberry, after he had recognized the Palaeozoic cycles in Ohio, applied the same theory to the Mesozoic deposits of the south-west, in particular to the Trias of New Mexico, and the Cretaceous of Colorado, Kansas, and Texas [3].

The processes of nature, says Newberry, are so multifarious that they easily conceal an underlying simplicity. Thus in some formations, particularly in the Coal measures, we may discover smaller cycles within the greater, that is, periods of rest or of regression within the general course of movement.

But if we accept these conclusions, and consider the detailed succession of a sedimentary series in its dependence on the great laws which govern the conditions of deposit, then the mode of stratification, and even each individual stratum, gain, as terms of a great rhythmical process, an importance hitherto not attributed to them [4].

That reservation which I made, with regard to the chronology of terrestrial faunas, holds good in so far as an alteration in the terrestrial fauna is not necessarily contemporaneous with an alteration in the marine fauna; but the great works of Marsh and Cope show already clearly enough to what a large extent the Tertiary land faunas of North America correspond with those of Europe. This fact is particularly instructive, since it demonstrates, even more forcibly than a consideration of the marine deposits, the simultaneous appearance and disappearance over vast areas of whole communities, of whole economic unities; the same phenomenon which Heer long ago happily designated 'the periodical recoinage of organisms.'

In Europe the great local variations in the characters of the deposits

[1] E. Mojsisovics v. Mojsvár, Die Dolomitriffe von Südtirol und Venetien, 8vo, 1879, p. 9.

[2] Dawson, Acadian Geology, 8vo, 1868, p. 137.

[3] Newberry, On Circles of Deposition in Secondary Sedimentary Rocks, American and Foreign; Proc. Lyceum Nat. Hist., New York, 2nd ser., No. 4, March 16, 1874, pp. 122–124.

[4] H. O. Lang, Ueber Sedimentärgesteine aus der Umgebung von Göttingen; Zeitschr. d. deutsch. geol. Ges., 1881, XXXIII, p. 273, Anm.: 'The expression stratification is . . . used to designate a phenomenon which is regarded as the result of *periodicity* in the conditions of formation.'

which furnish the remains of terrestrial animals—far more marked in this continent than in the United States—obliges the investigator to trust almost exclusively, certainly to a far greater extent than in the case of marine deposits, to organic remains for his chronological and stratigraphical conclusions. But it is scarcely necessary to remark that, while the characters of the terrestrial fauna afford a most valuable passive criterion, yet it is the physical causes of faunal transformations which will, when once they are recognized, form the only true basis for a delimitation of chronological periods.

These physical causes are probably very different in kind. As our brief account of the fluctuation of opinion in the last decennium or so has shown, the cause of the changes in the organic world has been sought mainly in movements of the earth's crust. The advance which has been made in our knowledge of the structure of the great mountain chains does not, however, bring us any nearer an understanding of this supposed connexion. The manner in which contraction of the earth's crust manifests itself on the surface of the planet, in the formation of folds and faults, does not accord with the hypothesis of moving continental masses, which, over wide areas, repeatedly ascend and descend in a slow and uniform manner. The similar development of the sedimentary series on both sides of the Atlantic Ocean, and the correspondence in the gaps of this series, cannot be explained in this way. When, in some of the best accounts of the structure of a mountain chain, we find, side by side with an exposition of the formation of the folds and fractures, an appeal made to supposed 'elevations in mass,' independent of the formation of the mountain chain, to account for some incompleteness of the series, it cannot fail to strike us that this is an assumption at variance with the rest of the explanations. We are left with the impression that phenomena essentially different in character have not been sufficiently distinguished from one another.

Let us consider the contrast between Élie de Beaumont's conception of the limit of a formation, and the views on which Beyrich based his classification of the middle Tertiary deposits. This contrast finds its clearest expression when to the term *dislocation* we oppose that of *transgression*.

A dislocation, whether it consists in folding or faulting, is limited to a definite mountain system, often even to a very small part of it; a transgression extends over a large part of the earth's surface. The intensity of a dislocation is subject to very rapid local variations; in a transgression, difference of intensity, within the limits of a single region, can hardly be distinguished, and a transgression may often extend over large areas in complete concordance with the underlying beds. The dislocated stratum was already in existence before the occurrence of that event, into the nature of which we are about to inquire; the transgressive stratum was

formed after or during that event. Investigations into the structure of great mountain chains have in recent times given us a continually deepening insight into the causes of dislocations; the question of transgressions still forms the subject of opposing theories.

That dislocations are the result of true movements, that is, of relative displacement of various parts of the planet, needs no explanation, the word itself expresses it. But this is not true of transgressions, nor has the word been chosen with this intent.

Under various forms the theory has long been maintained that along with the movements of the earth's crust, changes take place in the form of the surface of the sea. The remarkable extension of certain transgressions leads us to return to this view. A close investigation of the most recent events, such as are indicated by ancient shore-lines situated above the existing sea-level, can alone lead to definite results. But even a hasty consideration of such strand-lines suffices to show their complete and absolute independence of the geological structure of the coast. In Italy the lines of former sea-levels are met with on the various promontories of the Apennines in undisturbed horizontality, here on limestone, there on the ancient rocks of Calabria, here once more on the ash cone of Aetna. The complete absence of any relation between the ancient shore-lines and the structure of the mountains may be proved by hundreds of examples. But the supposition of a uniform elevation or depression of a continent, so complicated, and divided into so many fragments, without any mutual displacement of the parts—a supposition necessary to explain the horizontal course of these lines on the separate portions of a mountain complex—cannot be brought into harmony with our present knowledge of the structure of the mountains themselves. Thus this circumstance, too, leads us to infer independent movements of the sea, that is to say, changes in the form of the hydrosphere.—

Finally, let us suppose that our imaginary observer, wanderer, and listener should now leave the lecture room, and seek instruction as to the true nature of a geological formation in our abundant literature. If he thought it worth while to open the book which I now offer to publicity, he would not find in it an answer to his question. This answer is the great task of the next generation of investigators. Here we will only attempt by a critical synthesis of new observations to dissipate many ancient errors and to prepare the way for an unprejudiced survey.

With this object the present work is divided into four parts. The first treats of the *movements in the outer crust of the earth.* It falls into several chapters, more or less independent of each other. The first of these discusses the Deluge, the greatest natural phenomenon of which we have record. This affords an opportunity of comparing a number of phenomena peculiar to the districts about the mouths of great rivers,

misconceptions concerning which have led to a mistaken interpretation of certain events, such, for example, as those which occurred in the Rann of Cutch. The next chapter deals with various seismic areas in the Eastern Alps, South Italy, and the mainland of Central America; after this an inquiry is made as to whether a really permanent elevation of the ground occurred during the earthquakes in Chili. Then follows an attempt to survey the various kinds of dislocations; next a chapter on volcanos; finally a brief discussion of the relations which may exist between the sensible movements of the earth and the phenomena of dislocation.

The second part treats of the structure and history of a number of *mountain chains.* It begins with the northern foreland of the Carpathians, proceeds to the northern foreland of the Alps, and concludes with a long series of particular descriptions from all parts of the world.

This purely descriptive section is followed by a general survey of the structure of the surface of our globe and a more detailed exposition of the difference which exists between the Pacific and Atlantic basins.

The third part discusses the *changes of form in the surface of the sea.* A summary of the differences of opinion on this subject is first given. Next we propose to speak of positive and negative displacements of the shore-line, an expression free from theoretical implications; then in a series of descriptive chapters the traces of these displacements are followed around the continents and oceanic islands. A summary and discussion of these observations conclude this part.

The fourth part bears the title: *The Face of the Earth.* It sums up the contents of the preceding parts, and brings into relation the terrestrial changes which are deduced from them, with the changes which have taken place among the terrestrial faunas of the Northern hemisphere since the beginning of the Tertiary aera.

# PART I

# THE MOVEMENTS IN THE OUTER CRUST OF THE EARTH

## *CHAPTER I*

## THE DELUGE

**Oceanic floods. In the biblical story two accounts combined. Berosus: the Izdubar epic. Locality. Use of asphalt. Warnings. The catastrophe. Stranding. Conclusion of the event. More recent events in the lower courses of the rivers of India. Indus. Rann of Cutch. Ganges and Brahmaputra. Cyclones. Nature and extent of the Deluge. Classification of accounts. Berosus and Izdubar epic. Biblical accounts. Egypt. Hellenic-Syrian group. India. China. Conclusion.**

Charles Lyell has shown more clearly than any previous writer how Nature may attain great results by trifling means. But, as Ernst von Baer has shown in pregnant words, the standard for small and great, as well as for the duration and violence of a natural phenomenon, is in many cases derived from the physical organization of man. The year is a measure of time furnished by the planetary system; but when we speak of a thousand years we introduce the decimal system, and this is based on the structure of our extremities. We often measure mountains in feet, and we distinguish long and short periods of time according to the average length of human life, that is, according to the frailty of our bodies; and in like manner we unconsciously borrow the standard for the terms 'violent' or 'less violent' from the sphere of our personal experience.

Thus our judgment is moulded by our physical constitution, and we are prone to forget that the planet may be measured *by* man, but not *according to* man.

The enthusiasm with which the little polyp building up the coral reef, and the raindrop hollowing out the stone, have been contemplated, has, I fear, introduced into the consideration of important questions concerning the history of the earth a certain element of geological quietism—derived from the peaceable commonplaceness of everyday life—an element which by no means contributes to a just conception of those phenomena which have been, and still are, of the first consequence in fashioning the present face of the earth.

The convulsions which have affected certain parts of the earth's crust, with a frequency far greater than was till quite recently supposed, show clearly enough how one-sided this point of view is. The earthquakes of



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the present day are certainly but faint reminiscences of those telluric movements to which the structure of almost every mountain range bears witness. Numerous examples of great mountain chains suggest by their structure the possibility, and in certain cases even the probability, of the occasional intervention in the course of great geologic processes of episodal disturbances, of such indescribable and overpowering violence, that the imagination refuses to follow the understanding and to complete the picture of which the outlines are furnished by observations of fact.

Such catastrophes have not occurred since the existence of man, at least not since the time of written records. The most stupendous natural event for which we have human testimony is known as the Deluge. An attempt will here be made to investigate the physical basis of the ancient accounts. This attempt is founded on the cuneiform text, and owes much to the valuable assistance which the distinguished authority on these monuments of primitive culture, Dr. Paul Haupt in Göttingen, has so kindly rendered me; he has thrown light on many obscure points in the ancient texts, and has furnished me with a new translation of several important passages.

In the legends and holy books of antiquity there are numerous accounts of great natural phenomena. In the traditions of Northern Europe references to volcanic eruptions predominate; but stories of devastating floods are extremely widespread both in the old and new world.

It must from the outset be clearly borne in mind that the part played by rain in these great inundations is of necessity entirely subordinate. Pluvial inundations by their very origin are restricted within certain bounds; even in their most violent forms they are narrowly limited in space, and they flow away following the slope of the valleys. Floods of immeasurably greater violence are caused by hurricanes, and yet more extensive are those occasioned by earthquakes.

On November 1, 1755, an earthquake occurred at Lisbon of such force that the waves to which it gave rise in the Atlantic Ocean extended as far as the Antilles. When, on December 23, 1854, Simoda in Japan was devastated by an earthquake, great waves crossed the North Pacific Ocean and broke on the coast of California [1]. A violent shock occurred near Arica on the Peruvian coast on August 13, 1868. From accounts of this, collected from far and wide, Hochstetter was able to show that the agitation it caused in the sea was felt north and south along the west coast of America, that the waves rose in turmoil about the Sandwich Islands for several days, and broke on the Samoan Islands, the east coast of

[1] Bache, Am. Journ. Sci. Arts, 1856, 2nd ser., XXI, pp. 37–43. Here the first attempt was made to determine the depth of the ocean from a study of the propagation of the disturbance.

Australia, New Zealand, and the Chatham Islands [1]. The French frigate *Néréide*, bound at the time for Cape Horn, encountered in latitude 51° S. great packs of freshly-broken jagged icebergs, which the mighty flood had set free as it penetrated beneath the Antarctic ice [2]. Eugen Geinitz has shown how during the earthquake of Iquique in Peru on May 9, 1877, the Pacific Ocean rose in great waves on the opposite coast from Japan down to the Chatham Islands [3].

Woe to the land in the vicinity of the shock which experiences such a flood! Such a visitation befell Callao in Peru on October 28, 1746. An observer who visited the place soon afterwards writes: 'Not the faintest trace of its previous appearance remains; heaps of sand and boulders alone mark its former site; it has become an extensive beach stretching along the coast. Some towers did indeed, owing to the strength of their walls, for a time withstand the force of the earthquake and the violence of the concussions; but hardly had the unfortunate inhabitants recovered from the first shock of their terror, when the sea suddenly began to swell, and continued to rise to such an extraordinary degree and with such tremendous force, that—although Callao stood upon a hill, which insensibly increasing in elevation extends as far as Lima—yet nevertheless the water, hurling itself down from the height it had reached, rushed violently forwards far above the coast-line and covered everything in one immense flood; most of the ships which lay at anchor in the harbour were shattered, the rest were raised above the level of the walls and towers, driven forwards, and left stranded far away on the other side of the town. At the same time all the houses and buildings covered by the flood were torn away from their very foundations. . . .[4]'

Of 5,000 inhabitants only about 200 survived.

Occurrences of this kind are by no means rare. The sea retires to a distance, rises in a long towering ridge, and then plunges in a devastating flood over the land; the rivers are forced backwards, the towns laid waste. The extent of the disaster depends largely on the outline of the coast and the height of the land. Particularly striking instances of such floods have occurred of late years in South America, and Lyell was probably right when he attempted some years ago to explain the flood legends of the Araucanian

[1] F. v. Hochstetter, Ueber das Erdbeben in Peru am 13. August 1868, und die dadurch veranlassten Fluthwellen im pacif. Ocean; Sitzungsber. Akad. Wiss. Wien, 1868, Bd. 58a, p. 837; 1869, Bd. 59b, p. 109.

[2] Lettre de M. Essarts, Bull. Soc. Géogr., 1872, 6e sér., IV, p. 316, and Comptes rend., 1872, t. 74, p. 1126.

[3] E. Geinitz, Das Erdbeben von Iquique am 9. Mai 1877, und die durch dasselbe verursachte Erdbebenfluth im Grossen Ocean; Nova Act. Leop. Car. 1878, XL, pp. 385-444, 2 pl.

[4] A True and Particular Relation of the dreadful Earthquake which happen'd at Lima, &c. Published at Lima by Command of the Vice Roy, &c., 8vo, 2nd ed., London, 1748, pp. 146-148.

Indians from this circumstance[1]. The inhabitants of the Fiji Islands tell of a great flood, for many years after which they kept their boats in readiness, fearing a repetition of the occurrence, and Lenormant, in his excellent summary of the Deluge legends, remarks that this observation points rather to a tidal wave of the sea than to a universal deluge[2]. That accounts of great floods should be met with even on the most remote islands is, I think, rendered easily intelligible by the information concerning seismic sea-waves which has been collected within the last decade or so. In some of these traditions it is expressly stated that the flood was produced by the sea. Such seismic floods are, according to our present knowledge, only likely to occur in the case of islands, of low-lying coast-land, and of the lower parts of great river valleys.

For this reason it was found difficult to explain from natural causes the received interpretation of the biblical text. There was hesitation in admitting that a seismic wave could have carried Noah's ark to the top of Ararat, and the occurrence could not be explained by means of atmospheric precipitations.

In the biblical story the accounts of two independent writers are combined; their versions to a large extent repeat one another, but differ in matters of minor importance, and they are united in such a way as to be easily distinguishable. A most important point of difference lies in the designation of the divinity, the one writer making use of the name Jahveh, the other of the plural form Elohîm; there is also a marked difference in the style of narration. But the separation of the two accounts does not essentially advance our knowledge of the true nature of the event, and although an attempt has been made to show, by means of an ingenious method of exposition, that the words 'the mountains of Ararat' (Gen. viii. 4) do not indicate the mountain now known by this name, but the mountains of a district which we have no means of localizing, yet this does not appear to lead us to results of any value.

*The Izdubar Epic.*

From the fragments still extant of the writings of Berosus, a Babylonian priest who lived about 330–260 B.C., it has long been known that the tradition of a great flood existed in the lowlands of the Euphrates, and that in this tradition many of its features presented a striking resemblance to the biblical account. According to Berosus, who quotes the sacred writings of Babylonia as his authority, this catastrophe occurred in the reign of Xisuthros, son of Otiartes. Kronos informs Xisuthros in a dream that on the fifteenth of the month Daisios all human beings will be destroyed by a flood. He commands him to bury the sacred writings at Sippara, the city of the Sun, then to build a vessel, furnish it with provisions, and

[1] C. Lyell, Principles of Geology, 11th ed., II, p. 154.

[2] F. Lenormant, Les origines de l'histoire d'après la Bible, &c., I, Paris, 1880, pp. 487, 488.

enter it with his family and friends, taking with him as well four-footed and winged creatures. Xisuthros follows these instructions, the flood takes place, covers the country, and then abates; he sends forth birds that he may discover the condition of the earth and finally leaves the vessel, together with his family, and offers a sacrifice to the gods. Xisuthros as a reward for his piety obtains a place among the gods, and with him his wife, his daughter, and the steersman.

This is the substance of the account of Berosus as it is handed down by Alexander Polyhistor. 'Of the ship of Xisuthros,' he concludes, 'which finally stranded in Armenia, a portion still exists in the Gordyaean mountains in that country, and the people scrape off the pitch with which it is covered and use it as a charm against diseases. And when the others had returned to Babylon, and had found the writings at Sippara again, they built towns and erected temples, and thus Babylon was again populated[1].'

Within the last few years a series of most wonderful discoveries, exceeding all expectation, have recovered for us much of the ancient literature which flourished in the plain of the Euphrates, and among this a new and detailed account of the Deluge has been found.

The enthusiastic and successful efforts of English explorers such as Layard, Loftus, and G. Smith, and in particular of Hormuzd Rassam, have brought to light and restored to the scientific world the remains of the royal library of Nineveh. These consist of thousands of clay tablets covered with cuneiform inscriptions, which have been excavated from the ruined mound of Kujundjik. The writings include not only religious subjects, but embrace the most various branches of human knowledge. The greater part of the extant specimens of these ancient works were copied in the reign of Asûrbânîpal (670 B.C.) from originals preserved in the libraries of Babylon, Kutha, Akka, Ur, Erech, Larsa, Urpur, and other towns; this is in particular the case with regard to the tablets which we are about to discuss.

The account of the Deluge is, strange to say, not contained in those tablets which treat of the creation of the world, the fall of man, and the conflict of good and evil. It forms an episode in a great epic which tells of the deeds of the hero Izdubar. Several copies of this epic are known; they were made at the command of Asûrbânîpal from a much older text, which was probably inscribed more than 2,000 years before our aera, and which was preserved in the ecclesiastical library at Erech. G. Smith describes it rightly as a great national work. It consists of

[1] The fragments of Berosus which relate to the Deluge are to be found in Alex. Polyhist., Apollodorus, and Abydenus; they have been collected by G. Smith, The Chaldaean Account of Genesis, 8vo, London, 1876, pp. 37–47; in Lenormant, Origines, I, pp. 387–390, and in other places.

*twelve cantos, which, from their leading features, Rawlinson has ingeniously* compared with the twelve signs of the Zodiac. The career of the hero Izdubar (probably identical with the biblical Nimrod), as related in these twelve cantos, rests undoubtedly on an historical basis; but it receives from the comparison with the signs of the Zodiac an allegorical similarity with the course of the sun. The eleventh canto, which according to the order of the Zodiac corresponds to the sign Aquarius, contains the account of the Deluge. Izdubar has lost his friend Eabâni, he is ill, and wanders down the river to its mouth seeking his forefather Ḫasîs-Adra, who, having been rescued from the flood, has been placed there by the gods to lead an immortal life untouched by the hand of time. Izdubar finds his forefather and questions him as to his strange experiences, which the latter relates.

Of the narration of Ḫasîs-Adra several translations have been made. I will only mention those of G. Smith [1], with notes by Fox Talbot [2], of J. Oppert, F. Lenormant [3], and Paul Haupt [4]. In the following pages I have made use of Haupt's latest translation, which he has supplemented by much friendly information. For the portion Col. II, lines 1–24, which is unfortunately very incomplete and has not been rendered by Haupt, I have made use of the translation by Lenormant.

I shall confine myself to the following summary of Ḫasîs-Adra's narration, and refer the reader for the complete text, in so far as I do not quote it literally, to the works of the scholars already mentioned.

Col. I, 8–10. Introductory speech addressed to Izdubar.

11–17a. The great gods, in council in the ancient city of Surippak on the Euphrates, determine to cause a deluge.

17b–19. The god Êa, the lord of inscrutable wisdom, the god of the sea, was in the council of the gods and informs Ḫasîs-Adra of their resolve.

20–27. Êa's warning and injunction to build a ship on dry land.

28–31. Ḫ-Adra offers objections, he fears the scorn of the people and the elders.

32–45. Êa's renewed and detailed instruction, prophecy of the deluge, command to Ḫ-Adra to take with him corn, property, family, servants and maids, relations, cattle and wild beasts.

[1] G. Smith, in Trans. Bibl. Archaeol. Soc., 1873, II, pp. 213 et seq. and 1874, III, pp. 534 et seq.; further, The Chaldaean Account of Genesis, pp. 263-272.

[2] Fox Talbot, Trans. Bibl. Archaeol. Soc. 1875, IV, pp. 49-83.

[3] Lenormant, Origines, I, Append. v, pp. 601-618, and II a, p. 9, note; this translation is based on the previous works of Oppert.

[4] Paul Haupt, Der keilinschriftliche Sintfluthbericht, eine Episode des babylonischen Nimrod-Epos; Habilit.-Vorl. geh. a. d. Univ. Göttingen, 1880, 8°, Leipzig, 1881; and by the same, Excursus: Der keilinschriftliche Sintfluthbericht, in Schrader, Keilinschriften und Altes Testament. 2. Aufl., Giessen, 1883.

46–52. Ḫ-Adra consents, although no one has built a ship in this manner before; [here there are unfortunately many gaps].

Col. II, 1–24. [Unfortunately most incomplete.] The fragments preserved refer to the construction and equipment of the vessel.

25–29. Ḫ-Adra collects together all his possessions in silver and gold, and all the living seeds which he had; his household, the cattle, the wild beasts, and his relations he brings up into the ship.

30–36. Final warning by a voice (?). Ḫ-Adra's fear.

37–39. He enters the ship, closes it, and commits the great structure with its freight to the pilot Buzurkurgal.

40–50. Description of the phenomenon.

Col. III, 1–3. The description continued [incomplete].

4. Brother looks no longer for brother. [The fragment communicated by Fox Talbot, Trans. Bibl. Arch. Soc., IV, 129, which describes the terror and flight of men and beasts, does not belong to the Deluge story.]

5–7. Fear of the gods themselves; they fly up to the heaven of the god Anu.

8–18. Loud lament of the goddess Istar over the destruction of mankind; lament of the gods over the water spirits of the deep.

19–23. Duration of the storm and flood; subsidence.

24–30. Ḫ-Adra sails through the flood; corpses drift on the waters. Ḫ-Adra looks out and breaks into tears.

31. First appearance of land.

32–36. The ship strands on [the, or a] mountain of the land of Nizir and remains there six days.

37–44. Ḫasîs-Adra sends forth a dove (?), then a swallow, then a raven.

45–48. He leaves the ship with all his companions and prepares a sacrifice.

49, 50. The gods draw nigh.

51–53. Istar raises the great bows (?) on high, and vows not to forget.

Col. IV, 1–5. these days. All the gods may come to the offering except Bêl, who caused the flood.

6–9. Bêl's anger at Ḫ-Adra's escape.

9–11. The god Adar refers him to Êa.

12–22. Êa's justification. The innocent shall not suffer with the guilty. Beasts of prey, famine, and plague may destroy mankind, but never again a deluge.

23–30. Bêl pacified, enters the ship, lays Ḫ-Adra's hand in his wife's, raises both to the gods, and places them at the mouth of the rivers.

1. *The place of origin.* It is evident from our introductory remarks that the character of the scene of action—the question as to whether it was highland or lowland, the lower part of a great river valley for example—is of essential importance in a critical examination of this great natural phenomenon.

The eleventh canto of the Izdubar epic names two places definitely, the town Surippak as the abode of Ḫasîs-Adra, and the mountain of the country of Nizir as the place of stranding. We have now to consider more closely the place of origin of the catastrophe.

The first passage runs:

Col. I, 11. *The city of Surippak, the city, which as thou knowest, lieth on the bank of the Euphrates,*

12. *This [city] was [already] ancient, when the gods within it,*

13. *their hearts prompted the gods [to] send a deluge. . . .*

That the inhabitants of this town Surippak were a people skilled in ship-building is clear from the further contents of this canto, and from Ḫasîs-Adra's fear of their scorn. The town is placed by all writers on the lower portion of the river. Rawlinson seeks to show that it was situated somewhere in the neighbourhood of the present Howeiza, and describes it as an inland town, in so far as no town has ever been built on the sea-coast in the immediate neighbourhood of a big river such as the Euphrates, because navigation would be endangered by silting up [1].

The sea-coast of that time can, however, hardly have been identical with that of the present day. It is extremely probable that a considerable part of the plain in the neighbourhood of the present estuaries has been formed in the course of the last few thousand years. Pliny had already remarked (VI, cap. 26) that there was scarcely any other place where the formation of land by a river proceeded so rapidly. Beke attempted many years ago to determine the rate at which the coast advanced, from Arrian's account of the journey of Nearchus, and from Pliny's statement as to the position of Charax [2]. Loftus, Rawlinson, and all the more recent observers agree on this point; according to Loftus's description the only matter for doubt is whether the new land has been produced solely by the mud deposited by the river, or whether a slight retreat of the sea may not have contributed some assistance. According to the statements of this trustworthy observer, based on the evidence afforded by recent marine deposits which occur in the country, the coast-line of the Persian Gulf extended in comparatively modern times at least 400 kilometers further to the north-west than the present mouth of the Schatt-el-Arâb, and 240 kilometers further inland than the point of confluence of the Euphrates and Tigris at Korna [3].

[1] H. Rawlinson, Notes on Capt. Durand's Report upon the Islands of Bahrein, Journ. Roy. Asiat. Soc. 1880, XII, p. 205; also Lenormant, Orig., I, p. 393.

[2] C. T. Beke, On the former Extent of the Persian Gulf and on the comparatively recent Union of the Tigris and Euphrates, Phil. Mag., 1834, new ser., IV, pp. 107–112; Carter, Remarks, &c., op. cit., 1834, V, pp. 246–252; Beke, On the historical Evidence of the Advance of the Land upon the Sea at the Head of the Persian Gulf, op. cit., 1835, VI, pp. 401–408.

[3] W. K. Loftus, On the Geol. of Portions of the Turko-Persian Frontier; Quart. Journ. Geol. Soc., 1855, XI, p. 251.

The activity of the two great rivers in the formation of land is at any rate very considerable, and their fall in the whole of their lower course so slight that the tide has been observed in the Tigris as far as the village Abdallah-ibn-Ali, 280 kilometers, and in the Euphrates in the marshes of El-hammer, 298 kilometers inland from the sea [1].

Friedrich Delitzsch has collated all the historic texts which afford evidence of change in the region of the river mouths, and has even attempted to draw up a map showing its former condition [2]. He deduces from the account of Sennacherib's (705–681 B.C.) naval expedition against Elam that the Euphrates at that time possessed an independent mouth; and it seems to me that, in the case of the Tigris, yet more positive evidence on this subject, though relating to a still earlier period, is afforded by inscriptions which have been published by G. Smith; according to these a cutting was made under King Rim-sin from the Tigris to the sea, clearly in order to facilitate its discharge. We also possess a complete list of large waterworks constructed on the Tigris under Hammuragas (circ. 1500 B.C.), who succeeded Rim-sin on the throne; the inscriptions extol particularly a mighty dyke, which was built along the stream after certain great floods, and was called Kara-samas [3]. Such embankments must, however, have hastened the silting up of the existing inlet. In addition to this, the island of Dilmun lay opposite the estuaries, a fact to which Friedrich Delitzsch has called attention. For all these reasons it is now impossible to determine with any attempt at precision the rate of growth of the land.

These statements might perhaps lead us to assume that the rivers were completely independent at the time of the Deluge, but F. Delitzsch rightly calls attention to Ḫasîs-Adra's later dwelling-place, where Izdubar visits him.

Col. IV, 30. *Then they took me, and afar off at the mouth of the rivers they made me to dwell.*

'The mouth of the rivers' indicates clearly that the streams, if they were still distinct, discharged themselves into the sea at no great distance from each other.

The town of Surippak, even at that time extremely ancient, was situated above this district, which was silting up, and on the Euphrates, hence at some place which must now lie far inland in the plain.

2. *The use of asphalt.* In considering the question of locality a definite

[1] A. Schläfli, Zur physikalischen Geographie von Unter-Mesopotamien; Schweiz. Denkschr., 1864, p. 4.

[2] F. Delitzsch, Wo lag das Paradies? 8°, 1881, pp. 173–182; also Fr. Hommel, Die vorsemitischen Culturen, 8°, 1883, p. 196. W. Ainsworth also treated this subject in great detail many years ago, and found that at a period 4,200 years distant the alluvial land must have been about 70 miles distant from the present coast; cf. by the same, Researches in Assyria, Babylonia, and Chaldaea, 8vo, 1838, p. 194.

[3] G. Smith, Early History of Babylonia, Trans. Bibl. Arch. Soc. 1872, I, pp. 55, 59, 62; F. Mürdter, Kurzgefasste Geschichte Babyloniens und Assyriens, 1882, p. 88.

indication must be mentioned, which is repeated in the narration of Ḫasîs-Adra, in the fragment of Berosus, and in the Elohistic account of Genesis; this, as Ainsworth and others long ago recognized, points to a definite feature in the geological structure in the district of the Lower Euphrates[1]. I refer to the employment of asphalt in the construction of the ark, a fact which, it seems to me, has not been accorded its due share of importance.

In the first part of Col. II, which describes the construction of the ship and its mode of partition, preserved unfortunately only in a fragmentary condition, lines 9–11 run as follows:

Col. II, 9. *I saw clefts and added what was wanting;*
10. *three measures of pitch I poured over the outside,*
11. *three measures of pitch I poured over the inside*[2].

Berosus relates how in much later times the bitumen was scraped off the outside of the vessel and used as a curative.

Gen. vi. 14 reads as follows: *Fac tibi arcam de lignis laevigatis: mansiunculas in arca facies, et bitumine linies intrinsecus et extrinsecus*[3].

A small fragment of a clay tablet relates the childhood of the great King Sargon I, and begins thus: *Sargon the mighty King, the King of Agade, am I. My mother was a princess, my father I never knew. My father's brother dwelt on the mountain of the town Azurpiranu, which lies on the banks of the Euphrates. My mother the princess conceived me; in secret she brought me forth. She placed me in a little basket of rushes, with pitch she closed the door. She set me in the river, which did not drown me*[4].

In like manner Exod. ii. 3 relates that the little basket of reeds in which Moses was exposed was closed with pitch.

The valley of the Euphrates and Tigris is surrounded by hills of Miocene strata, rich in asphalt. Loftus gives a list of numerous localities where asphalt occurs.

Let us now compare the account of the pouring of pitch over the ark, both *within* and *without*, as expressly stated both in Genesis and the

[1] W. Ainsworth, Researches in Assyria, Babylonia, and Chaldaea, p. 89.

[2] Smith, Chald. Genes., p. 266; Lenormant, Orig., I, p. 606; P. Haupt, Keilinschriftl. Sintfluthbericht, p. 13. Dr. Haupt, in his glossary to the account of the Deluge (Schrader, Keilinsch. und Altes Test., p. 516), is inclined to translate these passages: 'Three measures of pitch I used in calking, and three measures of petroleum I brought into the interior.' The translation of the word qîru, 'exterior,' rests only on a conjecture, and in the first line the word kupru (pitch, asphalt), in the second iddu (petroleum, naphtha) is used; the latter corresponds, according to Haupt (id. loc. p. 510), to the Accadian äsir = glittering water (petroleum).

[3] The biblical texts are quoted according to the edition Tischendorf. I have no intention of entering here into the old controversy on the expression 'de lignis laevigatis'; on this point I refer the reader, among other works, to Beke and Carter, Phil. Mag., new ser., III, p. 103; IV, pp. 178, 280, and V, p. 244.

[4] Smith, Chald. Genes., p. 299; Delitzsch, Paradies, p. 209; Jos. Halévy, Revue critique, 1881, p. 482; Mélanges de critique, &c., Paris, 1883, p. 162.

Izdubar epic, with a description of the customs prevailing on the Euphrates at the present day, as given by an impartial authority, the engineer Cernik, who travelled through Mesopotamia some years ago in order to determine the course of a railway.

Cernik writes with regard to the transport of the naphtha obtained near Hit on the Euphrates: 'It is considered sufficient to make a rude basket-work, without a keel, and with rods of tamarisk-wood as ribs, the spaces being filled with straw and reed-work, and the whole construction plastered with a superabundant layer of asphalt both inside and out. Nevertheless these craft possess considerable relative strength. . . .[1]' At Hit on the Euphrates the same process is therefore in use to-day for the rapid construction of strong and water-tight vessels as was employed thousands of years ago by Ḫasîs-Adra.

In this district pitch was used for many purposes in ancient times. In the absence of quarry stones and lime, great buildings were erected of brick, and bitumen was used as cement.

Thus the well-known passage concerning the building of the tower of Babel reads as follows, Gen. xi. 3, *Dixitque alter ad proximum suum: Venite, faciamus lateres, et coquamus eos igni. Habueruntque lateres pro saxis et bitumen pro caemento.*

Herodotus describes in detail how the clay taken out of the ditch surrounding the town of Babylon was made into bricks and baked, how the wall was then built of these bricks, asphalt being used instead of mortar. But the asphalt was brought from Is, a town on the Euphrates, eight days' journey distant from Babylon. This is the present Hit[2].

Such brickwork is met with here and there amongst the ruins in great quantities, and Cernik relates that in the districts where asphalt abounds it is used in whole blocks for buildings.

The use of bitumen for the construction of the burning, perhaps even explosive, missiles, which were employed throughout the whole of Asia, was known in the very earliest times to which the cuneiform inscriptions extend. This is proved by the account of the contest of the god Merodach with the dragon Tiâmat, which seems to form a part of the Babylonian legend of the Fall, and yet more clearly by the biblical description in the apocryphal story of the dragon at Babel (Dan. xiv. 26). This is also the significance of the thunderbolts, with which Merodach, in the fight with the dragon, is represented in the bas-reliefs[3].

[1] Ingen. Jos. Cernik's technische Studien-Expedition durch die Gebiete des Euphrat und Tigris, bearb. und herausg. v. Am. Freih. v. Schweiger-Lerchenfeld; Petermann's Mittheil., Ergänzungshefte 44 and 45, 1875–1876, with 7 maps, i, p. 23.

[2] Herodotus, Clio, 179.

[3] Smith, Chald. Genes., pp. 62, 98; on the later development of the art of preparing these missiles, cf., in particular, R. Maclagan, On Early Asiatic Fire-Weapons, Journ. Asiat. Soc. Bengal, 1876, xlv a, pp. 30–71.

Let us now return to the building of the ship.

As the development of the various branches of architecture has been influenced by the nature of the stones at the command of the artist, so in the art of ship-building the character of the materials provided by nature has given rise to local peculiarities which, owing to the continued employment of the same materials, have persisted for long periods. In an instructive study Lane Fox has shown how slowly the advance has been made from the hollowed-out tree to the stitched boat, and from this to the use of pegs in boat-building, and, at the same time, how local peculiarities have persisted from the earliest periods down to the present day. The inhabitants of the island of Ké, to the west of New Guinea, who have a great reputation for their skill in ship-building, may afford us an example. They construct their boats in the old manner, binding on the ribs with cord, and only when these ribs, fixed according to ancient custom, have become useless, do they fasten on new ribs with nails in European fashion. The natives of the Samoan Islands and of Fiji calk their boats with the resin of the bread-fruit tree, those of the Kingsmill Islands with strips of Pandanus leaves; in certain parts of Siam a porous wood which swells in water is used for this purpose[1].

On the Euphrates pitch is still employed to-day as it was so long ago. But, besides vessels made with pitch, there are still used on the Euphrates those skins filled with air, and the rafts floated by skins, which are represented in Assyrian sculptures, and so fully described by Herodotus (I, 194). According to Herodotus these vessels could be used only to descend the rivers, and their chief freight was date wine. More than a century ago Rennell was astonished to find how precisely the description of Herodotus applied to the existing vessels still in daily use.

Ḥasîs-Adra's boat was black in colour, it was probably stitched; the abundant use of pitch in ship-building is a custom in the strictest sense of the word antediluvial, which has survived up to the present day.

3. *The warnings.* The information we derive from the text as to the physical occurrences of the Deluge may be divided into three groups, namely, the warnings, the event itself, and the conclusion. The difficulty in arriving at a more exact apprehension of the facts lies in the extensive personification of the forces of nature, but this difficulty is not, I think, altogether insuperable.

All the warnings proceed, it is to be observed, from Êa, the wise god of the sea and the deep. He took part in the council when the gods determined to cause a deluge, and he foretold the impending judgment to his faithful servant Ḥasîs-Adra.

[1] Lane Fox, On early Modes of Navigation; Journ. Anthropol. Inst., 1875, IV, pp. 399–435.

Col. I, 20. . . . *Hear . . . and give heed . . .*

21. *thou man of Surippak, son of Obara-Tutu (Obiartes),*
22. *abandon thy house, build a ship; save all that thou canst find of living creatures;*
23. *they wish to destroy the seed of life; preserve thou*
24. *and bring up living seed of every kind into the interior of the ship*[1].

What can have been the nature of these warnings from the sea-god? It seems to me that they can have been none other than minor floods, probably of seismic origin, repeated risings of the sea above its shores, which at the same time checked the Euphrates, awakened fear in the city of Surippak, situated at no great distance from the sea, and led to these measures of precaution.

The last warning, which immediately precedes the embarkment, is certainly of a somewhat different nature:

Col. II, 30. *Now when the sun had made the appointed time,*

31. *a voice (?) spoke: in the evening the heavens will rain destruction.*
33. *The appointed time is arrived,*
34. *spoke the voice (?), in the evening the heavens will rain destruction.*

It is remarkable that the otherwise universal personification of natural forces is not carried out here, but a voice is introduced as speaking, as though it were about to refer to a quite unusual phenomenon, perhaps a seismic rumbling, a *rombo.* We must abstain from further conjectures on this point. The lines quoted above are unfortunately preserved only on one of the Deluge tablets, and the text is much obliterated in both places where the word 'kukru,' which is here translated by 'voice,' occurs. The word is not found in other texts.

4. *The Catastrophe.* The most important part of the description is that dealing with the event itself; it is contained in the last lines of Col. II, and the first of Col. III; the latter are unfortunately much mutilated, and are supplemented only to a slight extent by a newly discovered fragment. After the passage describing how the ship is entrusted to the pilot Buzur-kurgal (II, 39) a division line occurs, then follows:

Col. II, 40. *Then arose Mû-śêri-ina-namâri*

41. *from the foundations of the heavens, black clouds*
42. *in the midst thereof Rammân caused his thunder to roar,*
43. *while Nebo and Sarru advance against each other,*
44. *the 'thronebearers' stride over mountain and plain.*
45. *The mighty plague god unfetters the hurricanes (?).*
46. *Adar causes the canals (?) to overflow unceasingly.*

[1] Haupt, in Schrader and other places, p. 61, and Gött. Nachr. 1883, p. 91.

47. *The Anunnaki cause floods to rise,*
48. *the earth they make to tremble through their power,*
49. *Rammân's great billow ascends to the sky;*
50. *all light is consumed in [darkness].*

Col. III, 1. *In one day . . . of the earth they lay [waste]*
2. *raging blew (ḫanṭis iziqâ-ma) . . . mountain (?) . . .*
3. *the . . . they bring up [to] battle against men.*
4. *Brother looks no more for brother, men trouble no longer about each other. In heaven*
5. *the gods fear the deluge, and*
6. *they seek a retreat, they ascend to the heaven of the god Anu.*
7. *Like a dog on his litter, the gods crouch together at the railings of heaven.*

These lines may be divided into the following groups: (*a*) Col. II, 40–45 refer to atmospheric phenomena; (*b*) 46–48 relate to the earth; (*c*) 49, 50 relate to both; (*d*) Col. III, 1–3 are unfortunately useless in their present incomplete state; (*e*) 4–7 describe the effect on men and gods.

This pragmatic arrangement works up the material in a forcible and effective manner to a climax, from the first appearance of a cloud on the horizon to the flight of the terrified gods.

(*a*) *The atmosphere* (Col. II, 40–45). Delitzsch interprets the expression in line 40 as, 'Water of the sunrise at dawn.' Rammân is the mighty god of the storm. A thunderstorm succeeds to heavy clouds, then a whirlwind. But what phenomenon of nature do the 'thronebearers' striding over mountain and plain represent?

Let us glance at Lower Mesopotamia. 'Although,' writes Schläfli, 'true storms are rare, whirlwinds are extremely frequent. Presenting in form the most startling resemblance to a waterspout and differing only in appearance by its whitish colour, the column of sand and dust raised by the wind sweeps majestically and lightly over the desert, losing itself above in the blue cloudless ether. . . . I remember counting eleven of these pillars of dust in one moment on my journey from Mossul to Bagdad in the middle of June of last year' (1861?)[1].

These pillars certainly sweep along like supports of the sky. But the dust-bearing storm may acquire stupendous power. An example of this occurred in Bagdad on May 20, 1857, when, with a south-west wind, the sun first became dim and then assumed the appearance of the moon. Then at five o'clock in the afternoon, according to the account of Dr. Dutheuil, a dark cloud of dust appeared; in one moment it had enveloped the whole town, and penetrated into courtyards and rooms. In less than a quarter of a minute the day was turned to the blackest night. The effect was terrifying, everything was in confusion even in

[1] Schläfli, Unt.-Mesopot., pp. 22, 23.

the houses. This darkness, deeper than that of the darkest night, lasted five minutes . . . the terrified inhabitants believed that the end of the world had come. Indeed the noise of the raging winds and the whole phenomenon were such as to inspire the minds of the stoutest with the fear of some great cataclysm. The dust was brick-coloured. The storm was felt in the most distant parts of the country. Schläfli calls it a dust-spout; Dutheuil does not think that it took the characteristic form of a spout, but believes that the moving mass of dust was distributed equally all over the country[1].

(*b*) *The earth* (Col. II, 46–49). The overflowing of the canals is a phenomenon which is readily explained by violent earthquake shocks, but it may have been increased on this occasion by the storm and the damming back of the rivers by the sea.

Line 47 appears to me to be of great importance. The Anunnaki are, as Haupt has shown, the spirits of the deep, of the great subterranean waters. It is they who convulse the earth, and 'bring floods' out of the deep. This rising of waters from the deep corresponds to the often quoted passages of the Elohistic account, Gen. vii. 11 *Rupti sunt omnes fontes abyssi magnae et cataractae caeli apertae sunt* (*All the fountains of the great deep were broken up and the windows of heaven were opened*), and viii. 2, after the occurrence, *Et clausi sunt fontes abyssi et prohibitae sunt pluviae de caelo* (*The fountains also of the deep were stopped, and the rain from the heaven was restrained*).

Thus the Izdubar epic states expressly that water came *out of the deep*, and in the biblical representation water from the deep is mentioned in two places as opposed to rain from heaven. But this rising of great quantities of water from the deep is a phenomenon which is a characteristic accompaniment of earthquakes in the alluvial districts of great rivers. The subterranean water is contained in the recent deposits of the great plains on both sides of the stream, and its upper limit rises to right and left above the mean level of the river, its elevation increasing in proportion to the distance from the river. What lies beneath this limit is saturated and mobile; the ground above it is dry and friable. When seismic oscillations occur in a district of this kind the brittle upper layer of the ground splits open in long clefts, and from these fissures the underground water, either clear or as a muddy mass, is violently ejected, sometimes in great volumes, sometimes in isolated jets several yards high.

This was the case on a comparatively small scale when on November 9, 1880, the alluvial plains of the Save near Agram were convulsed by a shock; it also took place to a somewhat greater degree on October 10, 1879, when an earthquake occurred in the meadows of the Danube near Moldowa; also on a much grander scale on the Lower Danube during

[1] Dutheuil, in Schläfli, loc. cit., pp. 23, 24.

the earthquake in Wallachia of January 11 (23), 1838, when the young alluvial land from the Dimbowitza to beyond the river Sereth was intersected by numerous fissures, from which the water gushed out in many cases 'fathoms high [1].'

The same phenomenon was observed in the alluvial plain of the Mississippi, when on January 6, 1812, its valley was convulsed by an earthquake in the neighbourhood of the town New Madrid, situated a little below the confluence of the Ohio. We possess a graphic and instructive account of the oscillation of the ground and the fractures thus caused from the pen of an eye-witness, Bringier. The water that had filled the lower cavities, in forcing its passage through, blew up the earth with loud explosions. It rushed out in all quarters, bringing with it an enormous quantity of carbonized wood mostly reduced to dust, which was ejected to a height of from ten to fifteen feet. In the meantime the surface was sinking and a black liquid rose up as high as the horse's belly [2]. That a small standing lake, Lake Eulalie near New Madrid, was suddenly drained by fissures caused by the same earthquake, is a fact by no means contradictory to the statements made above [3]. The lake lay, as is often the case, on an impervious bed, and it flowed away into the subterranean water beneath.

On January 12, 1862, a violent shock affected the whole region south of Lake Baikal, and in particular the delta of the river Selenga which flows into the lake. The steppe to the east of the Selenga, on which there was a settlement of Buriats, sank over an area of twelve kilometers in length and from 9·5–15 kilometers in breadth, water burst forth on all sides, as well as from the springs, and finally the great depression which had been formed was filled completely by the waters of the Baikal which flowed into it. In many places new springs made their appearance, as for instance between the village of Dubinin and the steppe of Sagansk. In the town of Kudara the wooden lids of the fountains were hurled into the air like corks from champagne bottles, and springs of tepid water rose in places to a height of three 'sagenes' (6·4 meters). The earthquake extended southwards past Kjachta towards Urga, and the Mongolians were so terrified by it that they caused the Lamas to perform religious ceremonies, in order to appease the evil spirits which, as they imagined, were shaking the earth [4].

[1] G. Schueler, Bericht an das fürstl. wallach. h. Ministerium, &c., über die Erdspaltungen und sonstigen Wirkungen des Erdbebens v. 11. (23.) Jan. 1838, fol., Bukarest, 1838.

[2] L. Bringier, Notice of the Geol., &c., of the regions around the Mississippi and its confluent waters; Silliman, Am. Journ. 1821, III, pp. 20-22.

[3] C. Lyell, Principles of Geol., 2nd ed., II, p. 139.

[4] The detailed accounts of these remarkable phenomena by Lopatin, Semenof, Phitingof, and others have been collected by Perrey, Note sur les tremblem. de terre en 1862, p. 111 et seq. and 1863, pp. 67-92.

The earthquakes on the lower course of the Indus, Ganges, and Brahmaputra have afforded numerous examples of the violent ejection of subterranean water through the fissures arising in the alluvial ground. Some of these will be referred to later.

These floods which the Anunnaki bring up from the depths, the fountains of the deep mentioned in Genesis, offer in my opinion a conclusive proof to the geologist that we are here dealing with a seismic convulsion in a broad river valley. Such phenomena have never been observed on any great scale except in extensive low-lying districts, where subterranean water is present, nor would they be explicable under any other conditions.

The interpretation of Col. II, 46–49, is therefore: fluctuation of the water in the open channels, eruption of the subterranean water of the Euphrates, accompanied by trembling of the ground.

(c) *Third group* (Col. II, 49, 50). It must be carefully noticed that there has so far been no mention of a great flood, although the fluctuation of the water in the canals and the spouting out of subterranean water are only observed before an extensive inundation. This is first mentioned in line 49, which reads:

49. *Rammân's flood ascends to heaven.*

In the very first allusion to the flood it already rises to heaven, and it is not Êa, the sea-god, who is named as instigator, but Rammân, the weather-god. Êa on the contrary offers friendly warning. The line quoted above can scarcely refer to the storm-lashed waves of an inundation caused by seismic disturbances. From waves of this kind the gods would hardly have fled to Anu's heaven, or, as some cuneiform scholars interpret, from the sphere of the planets to that of the fixed stars.

Sudden and terrible are the floods which are caused by cyclones. They only occur in proximity to the sea, either on islands or over the plains bordering the lower course of great rivers. With a breadth of hundreds of miles the cyclonic wave approaches the mainland, and if it is checked by the narrowing of the sea between convergent coasts, it rises to a steadily increasing height until it finally precipitates itself over the plain, carrying destruction before it. The havoc which such cyclones have wrought in the West Indies, and at the mouths of the rivers of India, has been terrible indeed. I shall quote examples later where the loss of human life in a single night was estimated at from one to two hundred thousand souls. As a rule unusually heavy falls of rain, described by observers in our own times as 'deluges,' take place, particularly in front of the advancing hurricane; at the same time violent thunderstorms frequently occur.

In certain instances earthquakes have occurred simultaneously with cyclones; this was the case near Calcutta in the fateful night of

October 11–12, 1737, to which I shall refer again later. When the 'great hurricane' of October 10, 1780, raged over the West Indian Islands, it raised the sea at St. Pierre in Martinique twenty-five feet high, and drowned on this island 9,000, on St. Lucia 6,000 persons, besides causing indescribable devastation: Sir G. Rodney expressed his firm conviction that such complete destruction of the strongest buildings could only be attributed to an earthquake, and that nothing but the violence of the storm had prevented the inhabitants from noticing the shocks [1].—

But to return to the text of the Izdubar epic.

Line 50 announces the setting in of darkness.

On September 2, 1860, the Prussian war-corvette *Arkona* fell in with a hurricane on the east coast of Japan, which she weathered gallantly. 'At eight o'clock [in the morning],' runs the report, 'it became so dark, that we could not see the end of the ship; sea and clouds appeared to engulf each other. The waves stood up like walls, and the storm lashed the foam through the air like close pelting rain; sea-water and rain-water poured in streams over the deck and through every aperture into the battery; wind and waves roared no longer, but everything trembled and thundered. . . .[2]'

That is Rammân, who raises the waves to heaven, till the trembling gods themselves fly to higher spheres, and who causes all light to be swallowed up in darkness. The words in which his intervention, following immediately upon the activity of the Anunnaki, is described, render it probable that simultaneously with the earthquake a cyclone from the Persian Gulf may have entered the Mesopotamian plain. In the same way a violent earthquake, which occurred in Bagdad on May 1, 1769, and which overthrew thousands of houses, was accompanied by a terrible storm and a 'deluge' of rain and hail [3].

The most destructive phenomenon of the present day, the cyclone, accompanied by an earthquake, is also that which corresponds most exactly to Ḫasîs-Adra's description of the greatest natural event of antiquity.

The next three lines, Col. III, 1–3, are, as we have said, unfortunately too fragmentary to admit of a closer interpretation. We only perceive from the single disconnected words, which are moreover differently rendered by the various translators, that they continue the description of the phenomenon.

Col. III, 4 depicts the effect on terror-stricken man, 5–7 that on the

[1] H. W. Dove, Ueber das Gesetz der Stürme; Poggendorff's Annal. d. Phys. u. Chem., 2. Reihe, XXII, 1841, p. 40.

[2] T. Reye, Die Wirbelstürme, Tornado's und Wettersäulen, 8vo, 1872, p. 115.

[3] Richard, Hist. natur. de l'air et des météores, 12mo, 1771, VIII, p. 504.

gods; to my previous remarks on these lines I have nothing more to add.

5. *Further course and conclusion of the catastrophe.* Here follows the lament of the mother of men, the majestic goddess Istar, over the deadly war waged against mankind; and the gods lament with her the deeds of the Anunnaki; hereupon:

Col. III, 19. *Six days and seven nights*
20. *wind, deluge (hurricane), and storm keep the upper hand,*
21. *[but] at the dawn of the seventh day the storm abated, the deluge (hurricane), which a battle*
22. *had waged, like a [mighty] army,*
23. *was lulled; the sea subsided and storm and deluge (hurricane) ceased.*
24. *I sailed through the sea lamenting*
25. *that the dwellings of men were reduced to mud;*
26. *corpses drifted like trunks of trees.*
27. *I had opened a hatch, and as daylight fell on my face,*
28. *I shuddered, and sat down weeping,*
29. *over my face flowed my tears.*

Lines 19–23 treat of the duration and final cessation of the great catastrophe. The period of six days and seven nights is much shorter than the period given in the biblical account, and corresponds more nearly with the duration of similar events at the present day.

In line 20 the original text employs three substantives: *sâru*, *abûbu*, and *mêḫû*. The first word is translated as identical with 'wind'; the third signifies, according to Paul Haupt, most certainly 'storm'; Lenormant says '*la pluie diluvienne*.' The second word *abûbu* has been interpreted in many ways. In the Hebrew text, the word *mabbûl* is used as the characteristic collective expression for the catastrophe of the Deluge, and this is no doubt the case with the word *abûbu*, e. g. I, 13; III, 20, 21, 23; and IV, 14, 17 et seq. G. Smith translates it '*deluge*,' Lenormant '*la trombe diluvienne*'; Paul Haupt had employed the word 'stormflood,' or 'flood,' but the translation 'waterspout' is, as he kindly informs me, not impossible[1].

[1] Dr. Haupt writes: 'What the Hebrew *nomen proprium* of the Deluge, *mabbûl*, really means is not quite clear. The usual derivation from *jabal*, "to stream," is not free from exception. E. Schrader, in the first edition of Die Keilschriften und das Alte Testament (1872), translated the Assyrian *abûbu* by "heaps of ears," "heap," and compared it with the Hebrew *abîb*, "ears." Oppert and Lenormant had previously translated the word by "éclair," *fulmen*. Schrader took his translation from Norris, Assyr. Diction., I, London, 1868. The frequently occurring phrase *kîma tîl abûbi ashup*, "like the hill of an *abûbu* I cast down," was rendered by Norris, whom Schrader followed, as "like a heap of corn I swept away." The translation "storm, whirlwind" was first employed by Smith (Assurbanipal, 56, 74). Praetorius adopted this rendering in the Zeitschrift der Deutschen morgenländ. Gesellsch., Bd. 28, p. 89, and compared it with the

There is a similar doubt as to the word *hâltu* in line 22; it only occurs in this passage, and was rendered by earlier translators as 'earthquake,' and by Haupt as 'army,' on account of the verb 'fights' (Haupt, Exc., pp. 73, 74). Haupt translates: '... the flood, which had waged a battle, like a [mighty] army, was lulled.' Lenormant, on the other hand, translates: *La trombe terrible, qui avait assailli comme un tremblement de terre, s'apaisa.*

Line 23. The sea subsided; according to Haupt, Exc., p. 74, literally: 'he made the sea to withdraw into its basin.' Dr. Haupt, to whom I am indebted for so much kind help in these studies, confirms this literal translation by two passages of the first tablet of the Izdubar epic. This would again go to show that the flood came from the sea, and we shall soon meet with further proof of this.

In lines 24–29 the raging of the storm has already ceased. With great vividness these passages describe the state of the earth after the great flood, the dwelling-places buried in mud, the drifting corpses, and the deep impression made on the minds of the survivors. We have now reached the stranding of the vessel.

6. *The stranding.* In the passages referring to this portion I owe some important alterations to the kindness of Dr. Haupt. The lines then read as follows:

Col. III, 30. *I looked towards the four cardinal points* [or, *wherever I looked*], *a terrible sea;*

31. *towards the twelve houses of the heavens* [i.e. *in all directions of the compass*], *no land.*

32. *The ship drifted* [*at will*] *towards the country of Nizir,*

33. *a mountain of the country of Nizir held the ship fast and let it go no further towards the summit.*

34. *On the first and on the second day the mountain of Nizir held the ship fast, and did not let it, &c.*

35. [*also*] *on the third and fourth day the mountain held, &c.*

36. [*likewise*] *on the fifth and sixth day the mountain held, &c.*

Arabic *habûb*, "strongly blowing, violent wind," from *habba*, "to blow violently" (whence also *habbâb*, "fine dust"). The expression *kîma til abûbi* he understood as "like a heap, a ruin, which the storm has destroyed." Pognon, L'inscription de Bavian, Paris, 1879, p. 93, says, on the other hand, "Quant à l'expression *til abûbi* que l'on rencontre souvent dans les textes, je crois qu'elle désigne un monticule inhabité et battu par le vent"; so also in the Glossary, p. 178. In the same year I translated the word in my Sumerische Familiengesetze, p. 19, 7, as "storm wave." Lotz, Tiglath-pilesar, 1880, p. 129, hesitates between "wave raised by the tempest" and "hill of quicksand." In my Commentary to the Deluge in Schrader's book I pointed out for the first time that *abûbu*, like the Hebrew *mabbûl*, is the proper name for the Deluge. From all this it is clear that *abûbu* can quite well be rendered by Lenormant's *trombe*.' This conception agrees so exactly with the observations of storms at the mouth of the Ganges at the present day, that I should have adopted Lenormant's view and used the word *cyclone*, had I not feared the objection might be raised that the rotatory nature of great storms was unknown at that time.

At the dawn of the seventh day Ḫasîs-Adra sends out a dove.

For line 31 Dr. Haupt follows the interpretation previously given by J. Oppert.

An inscription which records a military expedition of King Asûr-nâçir-pal gives us information as to the situation of the country of Nizir. It lies east of the Tigris on the other side of the Lesser Zab, somewhere between the thirty-fifth and thirty-sixth degrees of latitude. But the text, as quoted above, does not seem to me to render it necessary to assume that the stranding took place in the heart of the mountains, or even on a mountain peak, nor indeed does it afford any support to such a supposition [1].

The mountains which separate Persia from the Mesopotamian plain consist of a unilateral chain, the oldest members of which form the Elwend in the north-east; these are succeeded by folded ranges of Mesozoic and Nummulitic limestone; folded and overfolded Miocene clays, bearing gypsum, salt, and asphalt, form the outer zone of this great mountain range in the south-west.

The whole lower course of the Lesser Zab falls, according to Loftus, in the region of these Miocene foot-hills.

The passage in question in the inscription of Asûr-nâçir-pal reads as follows: *In the month Tischrît, on the fifteenth day, I left the town Kalzu and entered the district of the town Babitê. I left Babitê and approached the land of Nizir, which is also called Lullu-Kinipa. I took the town Bunasi, its stronghold, and thirty closed towns of its frontier. The men were filled with fear and withdrew to the inaccessible mountains. But Asur-nâçir-pal, who marched first in their pursuit, went in quest of them as though they were birds. He scattered their bodies abroad in the mountains of the Land of Nizir. He cut in pieces three hundred and twenty-six of their warriors; he took their horses. He killed the remainder in the gorges and ravines of the mountain. . . .* So Lenormant, Orig., II, pt. i, pp. 10, 11. According to Oppert, Expéd. Mésop., this is followed by: *The majestic summits of these mountains stand up like a dagger. Concealed from my warriors I ascended to their hiding-places. . . .* And a later passage reads: *I left the town Kalzu; I crossed the Lesser Zab, and I entered the country in the immediate neighbourhood of the town Babitê.*

Kalzu (Kakzi according to Oppert) is identified with Schamâmek near Erbil (Arbela), i.e. the province of Schemamlik at the foot of the Dehir Dagh.

[1] Delitzsch, Paradies, p. 105; Lenormant, Orig., II, pt. i, p. 6. There seems to me to be no reason to regard the Pic of Rowandiz, or indeed any mountain peak, as the place of the stranding; cf. Sayce, Cuneiform Inscript. of Van, Journ. Asiatic Soc., 1882, new ser., XIV, p. 393. The expression "mountain" is also discussed by Diestel, Die Sintfluth, 2. Aufl., 1876, p. 13 (Samml. wiss. Vortr. v. Virchow und Holtzendorff, VI, p. 137).

Comparing these statements with Cernik's description, we arrive at the following results:

The Assyrian king began his march at the same spot where, more than five hundred years later, the great army of Darius Codomanus fled before the victorious Alexander after the disastrous battle of Gaugamela. This place is about 290–325 meters above the sea-level. The town Babitê could be reached in the same day, and must have been in the immediate neighbourhood of the Lesser Zab. The expedition was directed to the east-south-east. The king had taken war-chariots with him, and must have crossed the river near the present line of route, i. e. not far from Altyn-Kjöprü. By the land of Nizir we must understand that country which is separated from the plain of the Tigris by the Miocene hills of the Karatschok Dagh and Baruwân Dagh, and further south by the northern portion of the Jebel Hamrin. Several rivers, among them the Lesser Zab, cross these hills in narrow gorges, and the banks of Tertiary conglomerate form in many places jagged cliffs of considerable height[1].

The altitude of these mountains, which border on the land of Nizir, is on an average 300 meters above the sea; the rivers flowing through them lie much lower. But I see no reason to suppose that these mountains were submerged.

The vessel drifts over the great plain, enters the low-lying region of the Tigris, and strands on a declivity of one of these Miocene foot-hills which border the plain on the north and north-east. It does not reach the summit, but its living cargo, thus rescued, disembarks and ascends the mountain, for in a later passage we read:

Col. III, 46. *I raised an altar on the summit of the mountain. . . .*

The fact that the vessel was driven inland from the sea against the course of the rivers, seems to me decisive as to the character of the whole catastrophe. If, as is generally supposed, the flood had been caused by rain, it would certainly have carried the ship from the Lower Euphrates to the sea.

But this generally adopted conception of the biblical narrative can hardly be justified even by the narrative itself. In the eighteenth century eminent exponents had already asserted that in Gen. vi. 17 and vii. 6 '*mijam,*' *a mari*, from the sea, was to be read instead of '*majim,*' *aquae*, waters (as is well known the vowels were originally wanting in the Hebrew text). More than a hundred years ago J. D. Michaelis, whom Bunsen describes as one of the founders of the new biblical criticism, made the following translation of the passages in question:

vi. 17. *But I will bring a flood over the earth from the sea, to destroy all living souls under the whole heavens.*

And further:

vii. 6. *Noah was then six hundred years old, when the flood from the*

[1] Cernik, Studien, I, pp. 37–48, and II, pp. 1–4.

*sea broke over the earth, and he went himself with his sons, his wife, and his sons' wives into the ship, to escape from the water of the deluge.*

On this he makes the very sensible observation: 'The Deluge must in fact have been caused chiefly by the sea, for the air cannot hold nearly as much water as would have been necessary, and consequently cannot send it down as rain [1].'

To this interpretation, which several eminent expounders of the Bible adopted in the eighteenth century, the objection is made that: 'the alteration from *majim* to *mijam* is unnecessary and inadmissible, because the rain also played an important part [2].' But it is hardly necessary to point out how much nearer this interpretation brings the biblical account into harmony with observations of similar events in modern times.

7. *Conclusion. Time of the occurrence.* The remaining lines of Ḫasîs-Adra's narration are extremely interesting owing to their close similarity with the corresponding parts of the biblical text, but they give us no information of importance on the questions we have here discussed.

The episode of the sending forth of the birds has been dealt with by Delitzsch and Eberhard Schrader, who lay stress on the greater originality of the Chaldean account and the surprising resemblance to particular lines of the biblical text. The great bows of Anu which the goddess Istar raises on high before making her vow, the rainbow of Genesis, confirm the rain. Êa, the god of the sea, appears as peacemaker, and it is he who demands of warlike Bêl, that he shall never again cause a deluge [3].—

According to what has gone before, we must consider the lower basin of the rivers of Mesopotamia as the scene of these events, from the town of Surippak, which lies on the Euphrates near the sea, to the flanks of the mountains of Nizir on the other side of the Tigris. But against this view the objection has lately been raised by an eminent authority, that the whole colouring of the Chaldean account is specifically Babylonian, and that this account is 'localized in Babylonia' by its very character. It is further observed that in spite of this localization it yet seems to have no clear connexion with the climatic conditions of the country; and indeed it must be observed, first, that the inundation stands in no relation to the periodic flood-tides of the rivers in November and in spring; secondly, that it is not easy to understand why a ship steered by a pilot should

[1] J. D. Michaelis, Deutsche Uebers. des Alten Testamentes mit Anmerkungen für Ungelehrte, 2. Aufl., II, Göttingen, 1775, pp. 15, 16, 41, 43; and by the same, Orient. und exeget. Biblioth., IX. Bd., Frankfurt a. M., 1775, p. 183. There are also observations by other writers pointing out the possible overflowing of the sea, as for example Delitzsch, Paradies, p. 212.

[2] A. Knobel, Die Genesis, 2. Aufl., 1860, p. 88; Aug. Dillmann, Die Genesis, 4. Aufl., 1882, p. 133.

[3] E. Schrader, Die Keilschriften und das Alte Testament, 2. Aufl., 1883, pp. 50-52. With the 'great bows (?) of Anu' cf. Haupt in Schrader, op. cit. p. 517.

travel so far to the north. The matter only becomes comprehensible if we suppose a belief in the northern origin of the new race of mankind to have survived as a traditional feature in the Babylonian legend. But that would be sufficient to prove that Babylon was not the original home of the story of the Deluge[1].

These objections seem to me to proceed from that, so to speak, inland conception natural to the inhabitants of the interior of a continent, which leads them to regard rain as the chief source of the flood, although, as we have already observed in the case of such great inundations, rain only appears as an accessory cause. The flood came, as do all great floods of the present day, from the sea; earthquakes and cyclones have no connexion with the periodic rising of rivers, and it was they which caused the ship to drift so far to the north.

It is not my purpose to inquire here into the statements made by Berosus, and in Gen. vii. 11, as to the day of the month on which the flood commenced, nor can I discuss Rawlinson's remarkable comparison of the cantos of the Izdubar epic with the signs of the Zodiac. Bosanquet believes that he has been able to determine the exact date of the Deluge by means of the observations on eclipses of the sun recorded by the ancients. This method places it in the year 2379 B.C.; I mention these figures merely for the sake of completeness. There is every reason to suppose that the catastrophe occurred at a much earlier date[2].

I will here leave for a while the consideration of the Izdubar epic and discuss events of our own times similar to that of the Deluge. The accounts of these in the last twenty or thirty years show that they are much more frequent than we, owing to our European position, are apt to assume. The inundations at the mouths of the Indus, and at that of the united Ganges and Brahmaputra rivers, have been selected as examples. We will afterwards return to the discussion of the catastrophe described by Ḫasîs-Adra, and then proceed to a brief examination of the Deluge-legends of other nations, which have afforded material for an attempt to show that the catastrophe embraced the whole surface of the planet.

### B. *Recent events in the lower courses of the rivers of India.*

Ḫasîs-Adra offers up a sacrifice; the gods assemble like flies over it and inhale the sweet savour. The mother of men, Istar, when she has raised the great bows (?) on high, vows never to forget these days, and

[1] A. Dillmann, Ueber die Herkunft der urgeschichtlichen Sagen der Hebräer; Sitzungsber. der k. preuss. Akad. Wiss. Berlin, XXI, 1882, pp. 436-499.

[2] Bosanquet, Synchron. History of Assyria and Judaea, Trans. Bibl. Arch. Soc., III, 1874, p. 19; and by the same, Chronol. Remarks on the History of Esther and Ahasuerus, op. cit. V, 1877, p. 264. On what untrustworthy premises these calculations rest may be seen from the statements made here concerning the time of Sargon (p. 64).

the wise Êa admonishes Bêl, exhorting him to visit on the sinner his sin and on the transgressor his transgressions, but never again to cause a deluge (*abûbu*). Lions may come, and hyenas, and famine, and plague to diminish mankind, but the Deluge is not to return.

Noah, too, offers up his sacrifice, and Jahveh smells the sweet savour thereof, and vows in his heart that he will never again cause universal destruction.

The bow is placed in the sky by Elohîm, and the bond of peace is sealed for all time with man and with all living creatures.

And the valley of the Euphrates, although often visited by earthquakes, has indeed for thousands of years seen no recurrence of such a flood. The mouths of the river have silted up and advanced further into the sea, the fertilizing channels are dry, the land is devastated; Jeremiah's frightful prophesies have been fulfilled in Babylon, the proud cities of her kings have become shapeless heaps of ruins, but a deluge has never again covered the land.

In the valleys of other great streams, however, we often see the Anunnaki at work, and feel the wrath of terrible Rammân. We will now leave the traditions of the past, and turn to the experiences of the present.

Springs have always been considered as favoured spots from the earliest times, and by all nations, but in hot and arid countries this is the case to a much greater extent than in the north. The processes of evaporation and infiltration were however unknown, and the attempts to explain the source of the supply were manifold. One of these imagined the waters of the springs to lie beneath the plain. These are the 'waters of the deep' which break forth and ascend during earthquakes; by discharging themselves over the surface of the ground they cause a considerable part of this surface to sink into the space they vacate. This was the origin, as we saw above, of the new sheet of water which took the place of the settlement of Buriats near the Baikal.

This eruption of subterranean water, followed by subsidence of the ground, has occurred on the largest scale in the valley of the Lower Indus, which is frequently visited by earthquakes.

We will first consider this example.

The mouths of the Indus extend over the broad flat coastland between Karáchi on the north-west and Lakhpat in the south-west. This plain is bordered on the right by the hills which run from the Khirthar mountains to Cape Monze near Karáchi. Even below Haidarábád, near Jerruck, and between Tatta and Pirputta the rocky masses of these mountains run down to the river, and hold it on the right side, while far above these places great branches are sent off from its left side. Under these circumstances the question as to where the head of the delta is situated may be answered in various ways: if we place it at Tatta we only include a relatively small

part of the broad alluvial plain, which has been built up by this mighty stream heavily charged with sediment.

The mouth of the main river is, as Tremenheere has shown [1], subject to movements of the sea, which are mainly directed to the north-west, so that a part of its sediments are carried into the immediate neighbourhood of Karáchi. The mouth itself is turned in the same direction. A number of dry channels between the Indus and the Narra, which branches off much higher up, indicates that the united discharge, and with it the formation of the delta, have advanced more and more to the north-west.

Cunningham ascribes this deviation to the right which affects all the channels of the Punjâb to the rotation of the earth, and fixes on the year 680 A. D. as the date at which it abandoned the bed of the river Narra. In the year 711 A. D. the main stream had already excavated its present bed near Rohri, but it then flowed to the east of Haidarábád, and does not appear to have passed to the west of this town before the year 1592 [2].

In the plain of the Indus great and populous cities have fallen a sacrifice to natural phenomena. They were destroyed often in a few moments, with thousands of their inhabitants, and the annihilation of the irrigation works, or even the deviation of the river, prevented the survivors from rebuilding them. The traveller who centuries later passes that way comes upon extensive ruins, and the storied sculptures of an abandoned capital, on the dry channel of the diverted river, and so lost to human knowledge that the discovery even of its name may be a worthy object for the zeal of the archaeologist.

'I travelled,' writes Ibn Batuta in the year 1333 of our era, 'through Sind to the town of Lâhari, which lies on the coast of the Indian Ocean where the Sind (Indus) flows into it. It possesses a great harbour, where ships from Persia, Yemen, and other countries anchor. A few miles from this city are the ruins of another town, where stones in the form of men and animals are met with in great quantities. The people of this neighbourhood say that in the opinion of their historians a town once stood on this spot, but its inhabitants for the greater part were so wicked that God turned them, their animals, their plants, and even their seeds into stone; and indeed there are almost innumerable stones in the form of seed.' Fossils of Nummulitic limestone are here classed along with sculptures. The passage probably refers to the remains of the famous seaport of Debal, which lay between Karáchi and Tatta.

The report of the existence of such towns is widely spread to the west

[1] E. W. Tremenheere, On the Lower Portion of the River Indus; Journ. Geogr. Soc., 1867, XXXVII, pp. 68-91.

[2] Cunningham, The Ancient Geography of India, I: The Buddhist Period, 8vo, 1871, pp. 251, 280.

and north-west; and many points of correspondence between Zobeïde's narration in the Arabian Nights and the local legends make it probable that this story refers to one of the ruined cities of the delta of Indus, perhaps to this very city of Debal [1]. Zobeïde relates how they started for Bussora by ship, and after twenty days reached the harbour of a great town in India, where they landed and found the king, the queen, and all the people turned to stone.

In 1854 Bellasis and Richardson visited the remains of Bráhmanábád, which lies much further inland, north-east of Haidarábád, on the dry bed of the Narra. It was once an extensive and populous town, built of burnt bricks, but is now a heap of ruins, in the midst of which the lower part of a mighty round tower still projects. Open places and the site of the bazaar may be recognized, and the first excavations revealed, under the layer of rubbish nearly a hundred years old, skeletons of the inhabitants in their houses, coins and cameos, sculptures which had escaped the destructive fury of the Mohammedan iconoclasts, and even chessmen skilfully and elaborately carved. The complete ruin of strong buildings, the absence of any sign of conflagration, the remains of the inhabitants themselves and of their property confirm the legend according to which the town was suddenly destroyed by an earthquake [2].

Near the mouth of the Khori, the most eastern of the arms of the Indus, lies the town of Lakhpat. Here terminate the hills of Cutch, which stretch along the coast from the south-east, and separate the *Rann of Cutch*, a south-easterly expansion of the plain about the river-mouths, from the sea.

The immense plain of the Rann is covered, during a south-west monsoon from Lakhpat, with salt water; during the floods of the Indus it is inundated with fresh water, conveyed by the channels of the Banas or the Luni; at other times it is dry, and is then strewn with great patches of salt of dazzling whiteness.

Wynne, who made the geological map of Cutch, describes vividly the oppressive silence and solitude in the Rann, where, with the rare exception of a fugitive herd of wild asses, no living creature is to be seen, and the air is filled with the most wonderful mirages [3].

[1] Cunningham, Anc. Geogr. I, pp. 299-301. According to Vyse, Geol. Notes on the River Indus, Journ. Roy. Asiatic. Soc., new ser., X, 1878, p. 323, the Narra is not to be regarded as an ancient bed of the Indus.

[2] A. F. Bellasis, An Account of the Ancient and Ruined City of Brahminabad in Sind; Journ. Bombay Branch of the Roy. Asiat. Soc., 1857, V, pp. 413-425 and 467-477.

[3] A. B. Wynne, Mem. on the Geol. of Kutch; Mem. Geol. Surv. of India, 1872, IX, p. 15. It is the more necessary in what follows to base conclusions on fresh and trustworthy observations of the facts, since a frequently quoted authority, General le Grand-Jacob, declares that the statements of the natives on important points are not to be depended upon. Trans. Bombay Geogr. Soc., 1866, XVI, p. 65.

Its very name, which is borrowed from Sanskrit, proves its great age. *Kachcha* denotes a marsh, and *Irina* (Rann), a salt desert. The great Chinese traveller Hwen Tsang, who visited it in the year 641 A.D., describes the district even at that time as low-lying and damp, and the ground as filled with salt [1].

The wonderful mirages of the Rann have been the source of many legends and fairy tales. The natives see in these the phantom possessions of a pious king, who succeeded so completely in restoring a golden age of virtue that his capital, freed from all impurity, gradually ascended to heaven. But in an outlying house an impure animal, a wild ass, had been forgotten. It betrayed its presence by braying, and this interrupted the ascent of the city; since then it hovers over the Rann between heaven and earth [2].

This Rann of Cutch was visited in 1819 by a violent earthquake, accompanied by changes in the surface of the ground, which have since been the subject of much discussion. In treating of these I follow literally the account of the actual events given by Alexander Burnes; it is the same account as that made use of by Lyell in his description [3].

Previous to the battle of Jarra in the year 1762, says Burnes, in which the inhabitants of Cutch defended themselves gallantly against an army from Sind under Ghulam Shah Kulora, the eastern branch of the Indus, commonly called the Pharaun, emptied itself into the sea by passing along the western shores of Cutch; and the country on its banks participated in the advantages which this river bestows throughout its course. Its annual inundations watered the soil, and afforded a plentiful supply of rice, the country on its banks being then known by the name of 'Sayra.'

These blessings, which nature had bestowed on this otherwise barren region, perished with the battle of Jarra; for the Sindian chief, irritated at the unsuccessful result of his expedition, returned to his country full of vengeance and inflicted the deepest injury on the country which he had failed to humble. At the village of Mora he threw up a mound of earth, or as it is called, 'a bund,' across that branch of the Indus which fertilized Cutch; and by thus turning the stream which so much benefited its inhabitants, to flow into other branches of the river, and by leading it through canals to desert portions of his own dominions, he at once destroyed a large and rich tract of irrigated land, and converted a productive rice country, which had belonged to Cutch, into a sandy desert.

[1] Cunningham, Ancient Geography, I, p. 304.

[2] Bartle Frere, Notes on the Runn of Cutch and neighbouring Region; Journ. Geogr. Soc., 1870, XL, p. 187.

[3] A. Burnes, A Memoir on the eastern Branch of the Indus, and the Run of Cutch, containing an Account of the Alterations produced on them by an Earthquake in 1819; also a Descript. of the Rann in Travels into Bokhara, 1834, III, p. 310; cf. also Baird Smith, Memoir on Indian Earthquakes, II, Journ. Asiat. Soc. Bengal, 1843, XII, 6, pp. 1027–1033. B. Smith supposes that there is a volcano in the neighbourhood, but this is ar error.

The mound which had been raised did not entirely exclude the water of the Indus from Cutch, but so impeded the progress of the main stream, that all agriculture depending on irrigation ceased. In process of time this trivial remnant of prosperity disappeared, and the Talpoors, who succeeded the Kaloras in the government of Sind, threw up other mounds; and about the year 1802 the erection of one at Ali Bunder excluded the waters of the Indus, even at flood-time, from the channel which had once conveyed them through Cutch to the sea. Since then, the strip of land which once formed the fertile district of Sayra ceased to yield a blade of vegetation, and became a part of the Rann of Cutch, on which it had formerly bordered. The channel of the river at the town of Lakhpat grew shallow, and above Sindri filled with mud and dried up. Lower down it changed into an arm of the sea, and was flooded at every tide.

There then occurred, as Burnes further relates, in June, 1819, a violent earthquake, by which some hundreds of the inhabitants of Cutch perished, and every fortified stronghold in the country was shaken to its foundations. Numerous fissures were formed in the Rann, from which for three days there issued immense quantities of black muddy water, and in the district of Bunni which bordered on the Rann the water gushed out from the springs until the surrounding country was flooded to a depth of six or even of ten feet[1].

At sunset the shock was felt at Sindri, the station at which the Cutch Government levied their customs, situated on the high road from Cutch to Sind, and on the banks of what had been once the western branch of the Indus. The little brick fort of 150 feet square was overwhelmed by an inundating torrent of water from the ocean, which spread on every side, and in the course of a few hours converted the tract, which had before been hard and dry, into an inland lake, which extended for seventeen [Burnes, sixteen] miles on either side of Sindri. . . . But it was soon discovered that this was not the only alteration in this memorable convulsion of nature, as the inhabitants of Sindri observed, at a distance of five miles northward, a mound of earth or sand in a place where the soil was previously low and level. It extended east and west for a considerable distance, and passed immediately across the channel of the Indus, separating as it were for ever the Phurraun river from the sea. The natives called this mound by the name of '*Allah-Bund*,' or *the Mound of God*, in allusion to its not being, like the other dams of the Indus, a work of man, but a dam thrown up by nature. . . .

These wonderful events passed unheeded by the inhabitants, for the deep injury which had been inflicted on Cutch in 1762 had so thoroughly ruined that part of the country that it was a matter of indifference whether it continued a desert or became an inland lake. A feeble and

[1] Burnes, Memoir, p. 324; also Bartle Frere, Notes, p. 192.

unsuccessful attempt was made by Cutch to establish a custom-house on the newly raised dam of Allah-Bund, but to this the Ameers of Sind objected, and Sindri being no longer tenable, the officers were withdrawn to the mainland of Cutch.

Matters continued in this state till the month of November, 1826, when information was received that the Indus had burst its banks in Upper Sind, and that an immense volume of water had spread over the desert which bounds the country to the eastward, had likewise burst every artificial dam on the river, and forced for itself a passage to the Run of Cutch. In March, 1827, that is to say eight years after the earthquake, Burnes travelled by water from Bhúj, the capital of Cutch, past Lakhpat, to the vast sheet of water which surrounded the ruins of Sindri.

The most important part in the further account of Burnes is the description of the Allah-Bund. To the eye it did not appear more elevated in one place than another, and could be traced both east and west as far as the eye could reach; and the natives assigned to it a total length of fifty miles. '*It must not however,*' Burnes expressly states, '*be supposed to be a narrow stripe* like an artificial dam, as it extends inland to Raoma-ka-bazar, *perhaps to a breadth of sixteen miles*, and appeared to be a great upheaving of nature. Its surface was covered with saline soil, . . . and it consisted of clay, shells, and sand. . . .'

So far Burnes. Since then the Allah-Bund has often been visited; measurements of its height have given as the result 10, 15, 18, and even 20½ feet, but Wynne points out that the measurements were taken from the level of the water at its foot, and this is variable. Observers agree on the decisive point, that the Allah-Bund *only presents the appearance of a dam when viewed from the south*, but has no fall, or scarcely any, to the north; *indeed one could hardly say that a northern side exists.*

The Allah-Bund is therefore not a dam, but a *step, a sudden drop, in the level* of the land.

The land situated above this step and asserted to have been raised has, in reality, suffered *no* change. Wynne justly points out, that if any considerable elevation of this area had taken place it would have been impossible in 1826 for the flooded waters of the Indus to again follow the bed of the Pharaun, which had been separated from the main stream by a dike in 1762, and by crossing the Allah-Bund to reach the valley of Sindri and the mouth below Lakhpat [1].

The country south of the Allah-Bund, therefore, together with the fort

[1] Wynne, Memoir, p. 43; also Blanford, Mem. Geol. Surv. Ind., VI, p. 31, and Journ. Asiat. Soc. Bengal, 1876, XLV, pt. ii, p. 95, and Medlicott and Blanford, A Manual of the Geology of India, 8vo, 1879, I, p. 421, note. It did not appear to me necessary to discuss here the report of a recent depression in the year 1845, since the author who records the fact does not himself regard it as proved. Cf. Quart. Journ. Geol. Soc., 1846, II, p. 103.

of Sindri, subsided during the earthquake of 1819 owing to a considerable eruption of subterranean water; the Allah-Bund is a sharp step, like a fault in the alluvial land, marking the limit of subsidence; above the Allah-Bund no change has taken place, as is clear from the unaltered fall of the rivers.

This simple interpretation of the facts agrees fully with the plain statement which Carless has given of them in the Memoir to accompany the Survey of the Delta of the Indus, 1837. He merely observes that the lower alluvial land is said, during the earthquake of 1819, to have subsided in several places to a depth of some feet, and that a little fort near the river in the upper portion of this plain was destroyed. He adds that the district is at present covered with water[1].

Charles Lyell considered that the Allah-Bund was formed by an actual elevation of the ground. I can never forget the valuable inspiration which in my earlier years I derived from intercourse with this remarkable and genial man, who was ever ready to acknowledge and rectify any errors of his own, yet I am compelled to express the opinion that his interpretation of the changes which have occurred in the Rann of Cutch, although it has found a place in many textbooks, cannot be maintained[2]. There is here no question of elevation of the land, nor, as I was once misled by other descriptions to suppose, of superficial folding, but it is simply a case of the eruption of subterranean water and the consequent subsidence of a sharply defined portion of the muddy ground[3].

There is thus a complete correspondence between this and the events which took place near New Madrid on the Mississippi and in the steppe of the Buriats near Lake Baikal.—

Let us now turn to a country which is visited both by earthquakes and by cyclones, and in which devastating floods from the sea have occurred repeatedly in recent times, namely, the plain which stretches along the northern coast of the Bay of Bengal. Here the Ganges and the Brahmaputra flow by many branching channels into the sea, and I will attempt to describe the main features of these estuaries in their present state before passing on to their history, and to earthquakes and cyclones. I shall follow, in the first place, the masterly description of this region by J. Fergusson[4], and supplement it from the account of Medlicott and Blanford[5].

[1] Carless, Memoir to accompany the Survey of the Delta of the Indus, in 1837; Journ. Geogr. Soc., 1838, VIII, pp. 328–366, particularly p. 364.

[2] C. Lyell, Princ. Geol., 11th ed., pp. 98–104.

[3] Entstehung der Alpen, 8vo, 1875, p. 152.

[4] J. Fergusson, On recent Changes in the Delta of the Ganges; Quart. Journ. Geol. Soc., 1863, XIX, pp. 321–54.

[5] Medlicott and Blanford, A Manual of the Geology of India, in part, I, pp. 391 and ff.

At a considerable distance outside the littoral zone of the Sundarbans runs the Five-fathom-line from the Balasore Roads, in the west, towards Chittagong in the east. The coast sinks gradually to the sea-floor, with the exception of a remarkable region lying nearly in the middle of the tract, and somewhat to the south-west, outside the mouth of the Haringota, in which great depths suddenly appear; this region is the 'Swátch of no ground,' in which, especially towards its western side, the sounding-line finds no bottom even at a depth of 200 or even 300 fathoms.

Within the Sundarbans there is a network of water-courses, all of which contribute to the formation of habitable land, and to the gradual filling up of the numerous and extensive 'jhils.'

The Hindus have developed a terminology much more perfect than our own to denote the superficial features of the ground, and it is a question whether many of their designations might not with advantage be more generally employed.

*Bhâbar* denotes among the Hindus an alluvial talus with a somewhat steep slope, the region of fans at the foot of the mountains in which the rivers descending from the Himálaya lose a part of their water or are even drained dry; *tarái* is the richly vegetated zone where the subterranean water of the Bhâbar reappears; the term *bhángar* is applied to elevated plains of older alluvial formation, as opposed to *khádar*, the low-lying alluvial plain properly so called, which is, as a rule, bordered by scarps of trifling elevation.

The Ganges and Brahmaputra enter the vast plain of the delta with an almost equal volume of water, yet the Brahmaputra carries an incomparably greater quantity of sediment, probably owing to its greater fall. Notwithstanding this, in the delta of the Ganges, the formation of alluvial deposits is much further advanced, and the greater part of the delta is in the condition of habitable bhángar, while the chief portion of the plain of the Brahmaputra consists of frequently flooded khádar. With this fact is connected the interruption in the outline of the delta on its eastern side.

Near Rájmahál the Ganges doubles the extremity of the mountain range, which is formed of older volcanic rocks, and this point, where the stream lies about 20 meters above the sea level, is regarded as the head of the delta. Fergusson rightly points out that since the time when the sea extended to Rájmahál and the formation of the delta began, a considerable change must have taken place in the rate of deposition near Rájmahál itself, and that with the diminution in the fall of the river the progress of sedimentation must have become extremely slow. Between Rájmahál and the sea the formation of land is accompanied by a continual alteration in the course of the channels, which are constantly bifurcating into many branches. The Ganges itself has in

historical times abandoned its original channel, the Bhágírathí, over more than half of this district; it is this, too, which the natives hold sacred, not the Poddah branch in which the Ganges now flows.

The changes which the Brahmaputra has undergone are of much greater importance.

To the north of Dacca there extends, over an area 112 kilometers in length, with a maximum breadth of 56 kilometers, a large piece of elevated bhángar, the *Mádhupur Jungle,* with a steep slope on the west 40–50 feet high, and on the east a gentle declivity.

To the east of the Mádhupur Jungle and of Dacca, the group of Sylhet streams flows down from Cachar, clear currents with but little sediment, which during the months of the rainy period increase under the influence of the monsoon to a prodigious volume; they are bordered near the Mádhupur Jungle by the Sylhet-jhils, large quiet sheets of water, and their union forms the Meghná.

When in 1785 Rennell attempted to make the first measurement of the district, the immense and muddy stream of the Brahmaputra flowed on the east of the Mádhupur Jungle, contributed to the silting up of the Sylhet-jhils, received the Sylhet rivers, and finally discharged itself by the Meghná into the sea. Now the stream flows to the west of the higher country of Mádhupur, and the older branch is only indicated, at least for the greater part of the year, by a chain of marshes and pools.

The Brahmaputra has thus approached the Ganges, and a struggle takes place between them, by which the Ganges is constantly forced into more western channels by the greater quantity of sediment which its adversary carries down.

Fergusson ascribes the diversion of the Brahmaputra to a local elevation of the region to the north of Dacca, the Mádhupur Jungle, and connects the clarification of the Brahmaputra in the Sylhet-jhils with the slower growth of the delta in the east. On the other hand, Medlicott and Blanford point out that a subsidence of the Sylhet-jhils would have produced the same result. On the whole they are inclined to assume that both the valley of the Brahmaputra in Assam and the region of the Sylhet-jhils have subsided in comparatively recent times, that the Mádhupur Jungle has alone escaped this depression, and that it represents the original level of the alluvial deposits of the Brahmaputra. They compare this case with that of the Rann of Cutch[1].

There is no doubt that considerable changes have taken place in historic times within this extensive plain, partly by an alteration in the course of the rivers, partly by silting up, and perhaps also by subsidence.

[1] Loc. cit. p. 409. At the same time the authors concede the possibility of a slight elevation to the north of Dacca.

The historic investigations of Beveridge, which extend over the last three hundred years, and which are based mainly on the accounts of Jesuits at the close of the sixteenth century, do not prove that the Sundarbans were then inhabited as has been supposed. But there were at that time two royal residences in the eastern plains, one at Bakla, which does not now appear to exist, and one at Ciandecan (Chánd Khán). Large districts in Backergunge and Jessore may certainly have been cultivated, again converted into jungle, and then restored once more to cultivation [1].

Arabian writings show that during the last few hundred years changes have occurred in the west of greater importance than those which took place in the east, and returning to the time of the Chinese traveller Hwen-Tsang, of whose descriptions we have made use in discussing the delta of the Indus, we see that in the seventh century of our aera a large part of the present delta did not exist. From the statements of this trustworthy observer, Fergusson even concludes that the Sylhet-jhils may possibly have been still salt and in direct communication with the sea. In any case he considers it certain that the seaports of that time, Sonargaon and Satgaon, were situated at the head of two bays or estuaries into which the Brahmaputra and Ganges still flowed, and that the whole of the present delta to the south of these places was then almost certainly a great salt-water lagoon. He thinks it probable that the Sundarbans then formed a sort of *lido* outside this lagoon, into which the Ganges discharged itself independently, instead of flowing to the east to unite with the Brahmaputra [2].

Yet earlier times are discussed in a treatise by Cameron, in which he attempts to show that the more elevated district of Tipperah, bordering the delta on the east, corresponds to the ancient Taprobane. I am not in a position to express an opinion on this point [3].

Along the whole of the lower course of the Ganges and Brahmaputra earthquakes are of frequent occurrence, and on April 2, 1762, a great part of the plain from Chittagong in the east for a long distance westwards and inland, and especially in the neighbourhood of Dacca, was convulsed by violent shocks. The rivers poured from their channels like a raging sea over the land; far and wide the surface of the country was broken up by fissures, masses of water spouted forth from the ground to a height of many feet, while the surrounding land subsided; islands near the shore

[1] H. Beveridge, Were the Sunderbans inhabited in ancient times? Journ. Roy. Asiat. Soc., Bengal, 1876, XLV, pt. 1, pp. 71–76.

[2] J. Fergusson, On Hiouen-Thsang's Journey from Patna to Ballabhi; Journ. Roy. Asiat. Soc., new ser., VI, 1873, p. 256. On the present condition of Sunárgáon cf. J. Wise, Notes on Sunárgáon, Journ. Roy. Asiat. Soc. Bengal, 1874, I, pt. 1, pp. 82–96 and map.

[3] A. M. Cameron, The Identity of Ophir and Taprobane, and their Site indicated; Trans. Soc. Bibl. Arch., 1873, II, pp. 267–288.

were completely engulfed, and some rivers diverted from their course to such an extent that the ships upon them were unable to continue their voyage[1].

On April 3, 1810, September 18, 1829, and November 11, 1842, earthquakes occurred at Calcutta. A few months before the last of these a cyclone had passed over Calcutta.

On January 10, 1869, a violent shock occurred in the province of Cachar, to the east of the Brahmaputra, and was the cause of great changes in the configuration of the alluvial land. Here, according to

FIG. 1. *Fissures and funnel-shaped apertures* produced by the earthquake of Cachar on January 10, 1869 (after Oldham).

Oldham, there extends over an area of many square miles a layer of hard clay, thirty to forty feet deep, resting on a stratum of bluish silt saturated with water. Fissures miles in length opened along the rivers, and the upper stratum of the alluvial land glided on its watery substratum down towards the rivers in masses miles in width. The silt forced its way up through the gaping fissures; first of all dry dust was projected with the violence of a cannon-shot, so that it looked like a cloud of smoke,

[1] An Account of an Earthquake at Chattigoan, trans. from the Persian by M. E. Gulston, &c., and several other accounts in Phil. Trans. for 1763, LIII, pp. 251-269.

but this was at once followed by stiff mud, which formed a lip about the opening and then flowed away.

When the earthquake was over the alluvial ground was seen to be intersected by great fissures, which in many places became real faults owing to the subsidence of one side of the surrounding land, so that the whole plain appeared to be covered with little escarpments, and between or on these fissures round or elliptical apertures resembling craters were formed, often surrounded by a wall of mud or sand. In the case of many of the larger apertures, however, the sand and mud had poured back into the opening after the eruption, and had torn away its borders in their downward course so that only an irregular funnel-shaped opening remained [1].

The lists which Colonel Keatinge has published regularly since 1874 show that the whole of Assam, and particularly the plain to the north and south of the Khâsi mountains, the valley of the Brahmaputra, and the region of the Sylhet, were for years, and perhaps still are, the seat of seismic disturbances [2].

Yet more terrible than earthquakes are the cyclones which from time to time come from the sea and rage over the plain lying about the mouths of these rivers. Many of them arise near the Andaman Islands, whence they travel to the north, north-west, or west, bringing destruction in their train. Sometimes they enter the mouths of the Meghnâ or the Ganges, bearing with them stupendous masses of water, and accompanied by torrents of rain; sometimes they descend on the east coast of the mainland as far down as Pondicherri, sometimes on the island of Ceylon.

In the night between October 11 and 12, 1737, one of these cyclones entered the valley of the Ganges and travelled many miles up the river. At the same time an earthquake occurred, and in Calcutta 200 houses were destroyed. Ships of 60 tons burden were carried inland over the trees. The water of the Ganges is said to have risen 40 feet above its usual level; the loss of human life was estimated at 300,000 souls [3]. This figure is an exaggeration, but the catastrophe was doubtless terrible.

H. Blanford has published a list of the cyclones in the Bay of Bengal from the year 1737 to the great cyclone of 1876, and shown that, in this

[1] Godwin Austen, Notes from Assaloo, N. Cachar, on the Great Earthquake of Jan. 10, 1869, Proc. Roy. Asiat. Soc., Bengal, 1869, pp. 91–103; Oldham, note, loc. cit. pp. 113–115, and by the same: Notice of some of the secondary effects of the Earthquake of Jan. 10, 1869, in Cachar, with remarks by R. Mallet, Quart. Journ. Geol. Soc., 1872, XXVIII, pp. 255–270, and in particular Oldham, The Cachar Earthquake, &c., Mem. Geol. Surv., India, 1882, XIX, pp. 1–98, with map and plate.

[2] Col. Keatinge, Record of the occurrence of Earthquakes in Assam; Journ. Roy. Asiat. Soc., Bengal, 1877–81, *passim*.

[3] R. Baird Smith, Memoir on Indian Earthquakes, II; Journ. Roy. Asiat. Soc., Bengal, XII, 1843, p. 1,040.

period of 139 years, 112 larger or smaller cyclones had agitated the sea and descended on the coast [1].

Without entering into any of the excellent descriptions of particular cyclones which have been given by English investigators, I will select a few examples from this list.

On May 19 and 20, 1787, a storm and storm-wave visited Coringa on the delta of the Godávari, and extended 32 kilometers inland; according to an approximate estimate 20,000 persons and 500,000 head of cattle were destroyed.

On October 19, 1800, a terrible hurricane and an earthquake occurred simultaneously at Ongole and Masulipatam on both sides of the mouths of the Kistna.

In June, 1822, a storm-wave swept over the eastern part of the Sundarbans, over Burisal and Backergunge; the cyclone is said to have advanced along its path only 85 kilometers in 24 hours; 50,000 persons are said to have lost their lives.

On October 31, 1831, a similar storm-wave devastated the extreme west of the plain of the Ganges, where it extends to the south from Calcutta towards Cuttack; 300 villages were swept away, and at least 11,000 persons drowned; it was followed by a famine, and the whole loss of human life from this occurrence was estimated at 50,000 souls.

On May 21, 1832, from 8,000 to 10,000 persons were drowned in a similar flood in the delta of the Ganges.

Between November 12 and 17, 1837, a storm and high sea advanced from the Andaman Islands to Coringa; the wave was eight feet high; 700 persons lost their lives in ships; 6,000 perished on the land.

For the description of the hurricane of October, 1842, which was more remarkable for the length of its course than for the devastation it caused, I follow the account given by Piddington [2].

The hurricane proceeded, as is so often the case, from the Andaman Islands; following a straight, due west course, it crossed the southern portion of the Bay of Bengal on October 22, 23, and 24, and on the last-named day, after five o'clock in the afternoon, its centre reached the east coast somewhat to the north of Pondicherri. It then changed its course, evidently diverted by the hills, and deviated a little to the south-west, and at midday of the 25th the storm-centre crossed the Western Ghâts through the Palgautcherry pass between Salem and Paniany. Here a division of the cyclone appears to have taken place. Two distinct cyclones appeared in the Arabian Gulf.

[1] H. F. Blanford, Catalogue of Cyclones in the Bay of Bengal; Journ. Roy. Asiat. Soc., Bengal, 1877, XLVI b, pp. 328–38.

[2] H. Piddington, Eighth Memoir on the Law of Storms in India; Journ. Roy. Asiat. Soc., Bengal, 1843, XII, pt. 1, pp. 339–399, two maps.

The southern branch proceeded to the west-north-west and overtook on October 27 at mid-day, already far beyond the Laccadives, the ship *Futty Salam*, in lat. 11° 5′ N., long. 69° 9′ E., and after traversing nearly a sixth part of the earth's circumference descended on October 31 in lat. 14° N., long. 61° E., not six degrees from the island of Socotra, with frightful violence on the ship *Seaton*, which it dismasted and left a helpless wreck. From this point the storm assumed a more north-westerly direction. This is plain from the fact that ships travelling between Socotra

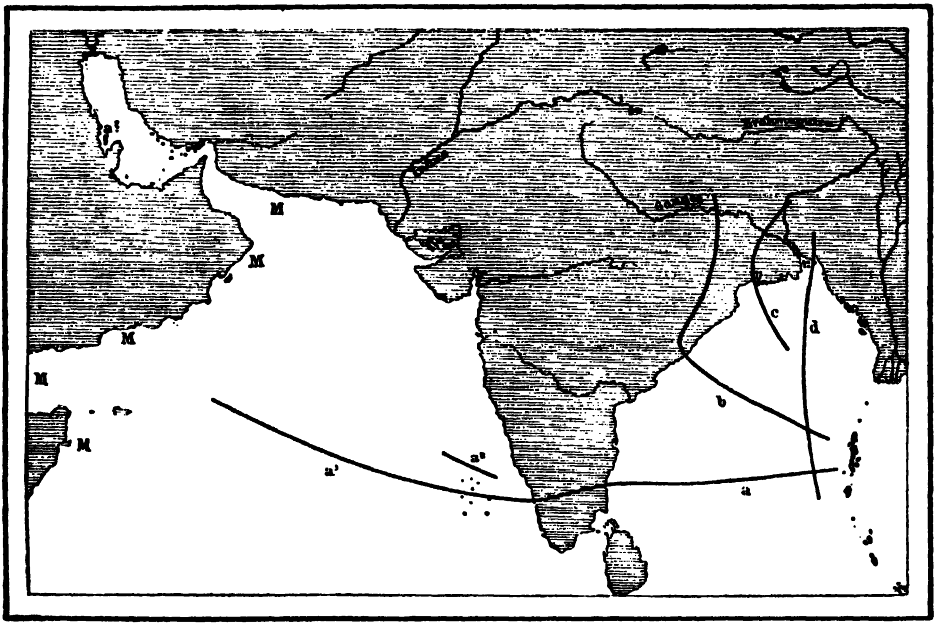



FIG. 2. *The path of some Indian Cyclones.*

a, a', a², *The Madras cyclone*, October, 1842; M, M, region in which ships went ashore; a ?, supposed continuation of the path into the Persian Gulf (after Piddington); b, *The Vizagapatam cyclone*, October, 1876 (after Elliott); c, *The Midnapore and Burdwan cyclone*, October 15 to 16, 1874 (after Willson); d, *The Backergunge cyclone*, October 29 to November 1, 1876 (after Elliott).

and this point only experienced the more distant agitation caused by its outer edges.

The northern branch seems to have travelled in a more north-westerly direction from the time it left the coast of India. Along the whole coast, from the entrance of the Persian Gulf to the Gulf of Aden and along the coast of the continent of Africa, even to the south of Cape Guardafui, a large number of vessels suffered shipwreck; an observer residing at Aden, Dr. Malcolmson, even supposed that this cyclone had crossed the Persian Gulf near the island of Bahrein. Unfortunately

we have no direct information concerning this the most northerly part of its course [1].

From October 2 to 5, 1864, a cyclone proceeded from the Andaman Islands towards the north-west; in the Hughli the wave washed away 48,000 persons and 100,000 head of cattle. Two great mail steamers were stranded in the fields, all the trees were deprived of foliage.

Blanford's gloomy list closes with the great *Cyclone of Backergunge* of the year 1876. Elliott has described this catastrophe in a separate report, from which we borrow the following account [2].

On October 23, 1876, an area of low pressure began to form in the south-east of the Bay of Bengal. The pressure continued to diminish during the next few days, and on the 26th and 27th violent vorticose winds were observed in this region. During the two following days the depression moved towards the north; on the evening of the 29th a violent cyclone had already formed. On October 30, at midday, the centre lay in lat. 14° N. and long. 89° E. The storm was then diverted to the north-north-east, while its rapidity and violence increased.

On November 1, towards three o'clock in the morning, it reached the mouth of the Meghná with a velocity of about 32 kilometers per hour. The area of calms in the centre of the storm seems to have been an ellipse from 24 to 29 kilometers across, and with the major axis transverse to the line of advance. Even at a distance of 300 kilometers from the centre the violence of the storm was so great that ships were dismasted. In the same night, during full moon, an unusually high tide entered the Meghná shortly before the storm and forced its waters backwards. It was not yet the time of full ebb when the retreating tide, surprised and overpowered by the flood caused by the cyclone and united with this in one stupendous wave, returned inland. The country to the north and north-west was flooded by the fresh water driven back by the sea, that to the east by salt water. Within a short time 3,000 square miles (about 141 geographical square miles) of the plain and of the large islands bordering it on the coast were covered with water to a depth of three to fifteen feet, in places even of forty-five feet. The centre of the storm advanced meanwhile to the north-north-west, reached the more elevated region of Tipperah, broke on it and dispersed.

The number of persons drowned was estimated by the governor, Sir Richard Temple, in his official report at 215,000 out of a total population of 1,162,000. Blanford, writing later, believes that about 100,000 persons were drowned. The groups of houses are as a rule surrounded by trees, otherwise the loss would have been greater.

[1] H. Piddington, loc. cit. p. 379.

[2] J. Elliott, Report of the Vizagapatam and Backergunge Cyclones of October, 1876, 4to, Calcutta, 1877; cf. also Hann, Oesterr. Zeitschr. für Meteorol., XII, 1877, pp. 81-87.

The descriptions given by the officials of the condition of the country after the catastrophe are terrible indeed; the houses were destroyed, the trees deprived of branches and leaves, and the country covered with pools of water and with the bodies of men and cattle lying together in heaps —a scene such as might indeed occur after a deluge had passed over the land. The area devastated by this great cyclonic flood is identical with that affected by the earthquake of 1762.

We have said above that the area of depression was broken up on the heights of Tipperah. Elliott expressly points out that the dispersion or deviation of a cyclone is brought about not by friction with the earth, but by the direct resistance of a range of hills. And indeed at the beginning of this same month, October, a smaller cyclone travelling from the Andamans towards the north-west arrived at Vizagapatam on the east coast, whence it turned northwards, diverted by the Eastern Ghâts; it continued on its course following the eastern slope of the mountain chain, crossed the Ganges between Patna and Monghyr, and even reached, although considerably diminished in force, the foot-hills of the Himalaya, having thus travelled through nearly eight degrees of latitude on dry land.

In the year 1737 at Calcutta, and in the year 1800 at the mouths of the Kistna, cyclones and earthquakes occurred in conjunction. Although these phenomena are distinct in their origin, and although the majority of cyclones are not accompanied by perceptible earthquakes, nor the majority of earthquakes by cyclones, yet the occurrence of earthquakes with a low barometer is so frequent that the attention of investigators could not fail to be directed to the circumstance. I will mention only a few of the observers who have pursued this branch of study. Julius Schmidt, for example, has compared the contemporaneous reading of the barometer in the case of many hundreds of earthquakes which have occurred in Greece of late years [1], Rossi has done the same for a number of Italian earthquakes [2], and George Darwin has even attempted to calculate the mechanical effect of the fall of the barometric pressure on the earth's surface [3]. Direct observations on this point do not seem to have led to any definite result, but the fall of the barometer in connexion with the earthquakes in Greece and Italy was much less than has been observed in the case of cyclones. According to our present knowledge of the subject we may assume that when that decrease of atmospheric pressure, which is the determining cause of a cyclone, occurs in a district already in a state of seismic

[1] J. Schmidt, Studien über Erdbeben, 2. Ausg., 1879, pp. 23-34.

[2] M. St. de Rossi, Meteorologia Endogena, 8vo, 1882, II, pp. 383-393; also Grablowitz, Sulla relaz. fra le altezze barom. ed i moti microsismici, Boll. Vulc. Ital., VIII, 1881, p. 33; Fagioli and Rossi, loc. cit. pp. 105-106.

[3] G. H. Darwin, On the Mechanical Effects of Barometric Pressure on the Earth's Surface; Phil. Mag., 1882, 5th ser., XIV, pp. 409-416.

disturbance, or in a condition about to terminate in an earthquake, then this decrease of pressure does not indeed give rise to the earthquake, but it hastens its appearance or even increases its violence.

### C. *Nature and extent of the Deluge.*

Let us now return to the Izdubar epic.

The phenomena which accompanied the great catastrophe are such as we only observe to-day on low-lying coasts and in the valleys of great streams, especially about the mouths of the latter. The Deluge as a whole can only have come from the sea; rain and subterranean water were merely accessory elements.

In this circumstance and in the local significance of the employment of asphalt lies a confirmation of the views of many distinguished archaeologists, who refuse to regard the account of the Deluge in the eleventh canto of the Izdubar epic as a borrowed episode, assigned after the event to the valley of the Euphrates, but who on the contrary see in it the record of a catastrophe which really took place in the very region mentioned in the text, at a time when the warping in the valley had not proceeded so far as at present.

It further follows that in Gen. vi. 17 and vii. 6 it is better to read '*mijam*' than '*majim*.'

The mouths of the Euphrates present all the conditions necessary for such an event, and to transfer it to the mouth of any other river is to remove it from the region to which existing tradition assigns it. We might, for example, relegate it to the united delta of the Ganges and Brahmaputra, which is at present so often visited by earthquakes and cyclones. But—apart from the fact that those who regard the traditional localization as doubtful would no doubt raise even stronger objections to this proceeding—the very frequency of great inundations in this region, true deluges indeed, is an argument rather against than for such an assumption. The accounts which we possess of the Deluge originated in districts in which such an event was extremely rare, almost indeed unheard of, and it was for this reason that it made so indelible an impression. The floods from the sea poured over richly populated regions, which had never before been, and, according to divine assurance, should never again be the scene of such an occurrence; this is an assurance which would certainly not be found in a tradition which had arisen in the frequently flooded delta of the Ganges.

The seismic element in the catastrophe is clearly represented by the warnings, the overflowing of the rivers, the breaking forth of the floods of the deep and the trembling of the earth.

Since that time Mesopotamia has often been visited by earthquakes. The most important seismic period begins in the year 763 B.C., the same year in which the eclipse of the sun occurred, the date of which (June 14,

763) was first determined by Hind and Airy and afterwards by Lehmann and by Oppolzer. It is on this date that the chronology of Assyrian antiquity is based[1].

This enables us to determine the dates of the following events noted in the administrative records of Assyria: 763 B.C., disturbances in Libzu; in the month of Sivan there is an eclipse of the sun; 762, disturbances in Libzu; 761, disturbances in Arbacha; 759, disturbances in Gozan; 758, tranquillity in the country. Later, in 746, disturbances are again mentioned, this time in Kalaḫ, the biblical Kelach (Gen. x. 11), situated to the south of Nineveh in the angle between the Upper Zab and the Tigris, where the village of Nimrûd now lies[2].

Bosanquet, following a suggestion of Rawlinson's, points out that by 'disturbances' earthquakes are to be understood, not risings among the people, and on this supposition he shows that the eclipse of the sun on June 14, 763, is the same as that which was foretold by the prophet Amos[3].

Earthquakes occurred at this period from Assyria to Palestine, and the years succeeding 763 were remarkable not only for earthquakes but for several eclipses of the sun. It is easy to recognize the effect which these terrifying phenomena have had on the sublime language of the prophets, who have mentioned or described them in several places, and invoked them as the signs of God's wrath. Even in the following century the recollection of these events was still alive among the people of Jerusalem.

The prophet Amos dates his vision explicitly, i. 1, *two years before the earthquake*, and he describes not only the shock, but the inundation from the sea; thus in v. 8; ix. 6 . . . *qui vocat aquas maris, et effundit eas super faciem terrae.* The prophet Sophonia, who wrote under Josias (616–586), paints in his moving and inimitable description of the *dies irae*, the fall of Sodom and Gomorrah, and all the horrors of a seismic catastrophe; and Zacharias says, xiv. 5 . . . *et fugietis sicut fugistis a facie terrae motus in diebus Oziae regis Iuda.* . . . This is the earthquake referred to by Amos.

But the great extension of this earthquake makes it improbable that the seat of its origin was in the plain of Mesopotamia. The name Arbacha, which corresponds to the Greek Arrhapachitis, the Armenian Albak, would

[1] P. Lehmann, in Eb. Schrader, Keilinschriften und Geschichtsforschung, 8vo, 1878, pp. 338 et seq.; Oppolzer, Monatsber. k. Akad. Wiss. Berlin, 1880, p. 184.

[2] E. Schrader, Keilinschriften und Altes Testament, 2. Aufl., p. 485. Here we may also refer to Justin, xviii, 3 *Tyriorum gens condita a Phoenicibus fuit, qui, terrae motu vexati, relicto patriae solo, Assyrium stagnum primum, mox mari proximum litus incoluerunt, condita ibi urbe, quam a piscium ubertate Sidona appellaverunt.*

[3] Bosanquet, On the date of the fall of Nineveh; Trans. Bibl. Arch. Soc., 1873, II, p. 155. Since the preceding pages have gone to press I learn from Dr. Haupt that the most recent investigations show the word *sîhu* to mean only a political rising, not an earthquake. This involves a modification of Bosanquet's theory.

lead us to the mountains on the Upper Zab, and hence bring us nearer the district of lakes Van and Urmiah, which is at present so often convulsed by earthquakes.

The Syrian desert is bordered on the north and west by two important seismic zones in which earthquakes have been recorded for many centuries.

The first of these zones begins on the Mediterranean coast near Antioch. This unfortunate town was the scene of the terrible catastrophe of December 13, 115, at which the emperor Trajan was present, and which has been described by Dio Cassius; it was again destroyed by a less violent earthquake in the month of May, 518, then on November 29, 528, again reduced to ruins, and finally on October 31, 589, became once more the grave of many thousands of people [1]. Since then it has often been the seat of earthquakes. From Antioch the seismic zone proceeds towards Aleppo and Mambedj (Hierapolis), crosses the Euphrates and is continued from Urfa (Edessa), probably in the direction of Diarbekr towards the mountain of Nemrûd or Sipan Dagh on the northern border of Lake Van. Here the great disasters of the years 715, 995, 1003, 1091, 1114, 1156 A. D., and a number of other great earthquakes occurred; in the last century I will only mention the destruction of Aleppo in the year 1822. In a masterly study on the earthquakes of the Armenian tableland, lately published, H. Abich represents this zone of seismic catastrophes as indicating the existence of a complicated system of fractures concealed in the depths of the earth's crust [2].

In the neighbourhood of Aleppo this zone is crossed by a second seismic zone trending to the south-south-west, which appears to be connected with the fault of the Jordan, and also with the Syrian coast-line. It begins near Malatiah on the Upper Euphrates and extends from Aleppo past Hamah (Epiphania) to Homs (Emesa) further to the south, and thence, passing through Baalbec and Damascus, it runs probably on both sides of the Anti-Libanon. The northern part of this zone is admirably described by the statements of the Arabian writer As-Soyúti, who records a series of seismic movements, which began with a tremendous disturbance in the year 552 of the Hegira (1158 A.D., according to other accounts 551 of the Hegira) [3]. Hoff has also collected accounts of these earthquakes and points out that they occurred in an area extending over four degrees of latitude [4]. According to As-Soyúti's statements the disturbances must have begun in the north, later on advanced towards Damascus, and then returned to Aleppo and Hamah.

[1] J. Schmidt, Studien über Erdbeben, 2. Aufl., 8, 1879, pp. 144 et seq.

[2] H. Abich, Geologische Forschungen in den kaukas. Ländern, II, 1882, pp. 390–449.

[3] As-Soyúti's Work on Earthquakes, transl. from the Arabic by A. Sprenger; Journ. Asiat. Soc., Bengal, 1843, XII, pt. 2, pp. 746, 747.

[4] v. Hoff, Geschichte natürlicher Veränderungen, IV, 1840, p. 217.

From these two zones, which surround the Syrian desert and intersect one another in the neighbourhood of Aleppo, those phenomena probably proceeded which in the year 763 B.C. and the following years agitated Assyria and terrified Palestine, which are chronicled in the administrative records of Assyria, and invoked in the books of the prophets.

But I do not think that the earthquakes which preceded the Deluge as warnings, or those which accompanied it, originated in these regions. Schläfli, during a visit to Mesopotamia which, it must be allowed, was brief, only experienced such earthquakes as were communicated to the land from a distance, either from the north or from the south, for example from the frequently convulsed Schiras in Persia.

For the earthquakes of the Deluge we must assume a southern origin, probably within the Persian Gulf.

Great atmospheric disturbances, vast falls of rain, storm, and darkness accompanied the earthquake. The darkness was not such as occurs temporarily, as for example during the earthquake of Lisbon, when the rubbish and dust of the falling town filled the air. Nor does anything justify us in assuming that the darkness was caused by the ash of a volcanic eruption. It was the darkness of the cyclone which had broken over the land.

The path of the cyclone of October, 1842, of which the last doubtful traces seem to have reached the island of Bahrein, does not entirely exclude the possibility that such a disturbance, arising at the Andaman Islands, the usual starting-point, might arrive in the Persian Gulf [1].

The eleventh month, to which according to Rawlinson's theory the eleventh canto corresponds, is not sacred to Êa, the god of the sea, nor to the Anunnaki, the spirits beneath the earth, but to Rammân, the storm god; the literal translation of the Akkadic name is, 'month of the curse of rain,' or briefly, 'month of the curse [2].'

The different impressions which such great natural phenomena produce on the various classes and branches of the human race is a matter not entirely without interest for the understanding of these phenomena.

On the Andaman Islands, which are so often visited by earthquakes, and which as we have seen are the centre of origin for most Indian hurricanes, the small remains of a primitive population have been preserved in isolation from the rest of mankind. These people have not even advanced to the worship of the sun. They know a demon of the woods, Eremchangala,

[1] The Korân mentions devastation by a storm of wind as a punishment, e.g. lxix. 6, 7: '*and the people of Âd were destroyed by the cold and violent windstorm which He sent against them for seven days and eight nights without interruption. Thou mightst see the people thrown down like fallen palm-tree trunks, and canst thou anywhere perceive survivors?*' Likewise li. 41, 42; liv. 19, 20.

[2] Lenormant, Orig., I, Append., tab. ii.

who causes earthquakes, and a demon of the sea, Juruwinde. Excessive fear of these is the only feeling which possesses them during such catastrophes. Here we see the trembling, terrified, naked creature when confronted with the great forces of nature [1].

Let us consider the attitude of a stage of civilization closely allied to this. On July 10, 1862, Accra on the coast of Guinea and a considerable part of the surrounding districts were convulsed by an earthquake. The Dutch merchant Euschart was on that day at Abomey, the capital of the kingdom of Dahomey. He was directed to the market-place. Here the king was sitting on his throne, surrounded by armed Amazons, and he explained that it was the spirit of his father who was convulsing the earth, because the ancient customs were no longer observed. Three chieftains captured in war were executed, that they might inform the spirit of the deceased king that the customs would in future be more strictly observed [2].

In the higher stages of civilization the expression of feeling is determined by the special education and calling of the individual.

We will begin with the defiant warrior. On September 4, 1596, there was a great earthquake at Kiyoto and Osaka in Japan. The fortress of Fushimi and many houses in Kiyoto, including the building in which the statue of the god Daibuzu was preserved, were overthrown. Then, as E. Naumann relates, Taiko Toyotomi Hideyoschi went to the temple of Daibuzu, placed himself before the fallen image, and with angry voice reproached the feeble god that so far from protecting the country he had not even the power to preserve himself; then he drew his bow and shot at the idol with arrows [3].

Very different is the attitude of the scholar. In the year 62 or 65 A.D. Apollonius of Tyana was on the island of Crete. He was on that coast of the island which is washed by the Libyan Sea, on a promontory in the neighbourhood of Phästus, and was engaged in conversation with a number of men who had come to do honour to the sanctuary on the promontory, when suddenly an earthquake took place. The roar of the thunder, says Philostratus, did not proceed from the clouds, but came from the depths of the sea, and the sea retired at least seven stadia, so that the crowd were afraid that in its retreat it would carry the temple with it, and wash them all away. Apollonius however said: '*Be comforted; the sea has brought forth new land.*' A few days later they heard that a new island had arisen between Thera and Crete [4].

[1] M. V. Portman, On the Andaman Islands and the Andamese; Journ. Roy. Asiat. Soc., new ser., XIII, 1881, pp. 475, 476.

[2] A. Perrey, Note sur les tremblements de terre en 1862, p. 156.

[3] E. Naumann, Ueber Erdbeben und Vulcanausbrüche in Japan; Mittheil. der deutsch. Gesellsch. für Natur- und Völkerkunde Ost-Asiens, 15. Heft., 4to, Yokohama, 1878, p. 17.

[4] Philostratus, Leben des Apollonius v. Tyana, IV, 34.

Different again is the attitude of the populace. Not only is defiance and power of observation lost, but often too all presence of mind. Men turn to the most injudicious expedients; they take refuge, for example, at the foot of pillars which are about to fall, as in the market-place of Sillein in Hungary, on January 15, 1858, and in the earthquake of Calabria, on February 5, 1783, when according to Hamilton's records 2,473 persons lost their lives owing to the fact that they sought refuge on the flat sea-shore near Scylla. It has often happened after earthquakes in more recent times, that tanks have been erected simply in order to make certain that the oscillations of the earth had really ceased, since a continuance of the oscillations seemed to be observed, and those who have read descriptions of the dejection of the survivors after the great earthquake of Lisbon on September 1, 1755, will fully understand Ḫasîs-Adra's feelings after the Deluge.

With the first ray of sunlight he opens a hatch and bursts into tears. Rescued himself he at once offers a sacrifice to the gods. Remembering how he had built his ship in defiance of the scorn of the populace[1], the repeated swellings of the sea which he had observed before the flood appear to him now as so many warnings from the kindly sea-god, while after such darkness the many-coloured rainbow becomes a sign of peace in nature, and of the propitiation of the gods.

All that is marvellous in this account disappears before the effect of those feelings which might still move the heart of man in similar circumstances, and in recognizing this we perceive as well that since that remote period, amidst the change of so many things, the human heart has remained the same. And it is just in these touching passages that the simple story of Ḫasîs-Adra bears the stamp of truth.

The ship's captain who has been so fortunate as to escape a cyclone with nothing worse than a dismasted vessel notes the rising barometer and is reassured; whatever his other feelings may be they are not entered in the records of the log-book. But when on October 10, 1780, during the war between England and France, a great cyclone passed over the Antilles, leaving a broad path of destruction in its train, dispersing and shattering the fleets, and casting up two English ships on the coast of Martinique, then the French commander, Marquis de Bouillé, sent the rescued Englishmen back to the hostile governor of Santa Lucia with the remark that he could not retain as his prisoners the victims of a general catastrophe[2].

[1] It is strange that this incident, which is foreign to the Bible and to all other pre-Christian accounts with the exception of the Izdubar epic, recurs in the otherwise incomplete account of the Korân, xi. 40, 41: '*So he made the ark, and whenever the elders of his people came by they mocked at him. He spoke: If ye mock at us, truly we will mock at you as ye mock now, and ye shall know it certainly.*'

[2] H. W. Dove, Ueber das Gesetz der Stürme; Poggendorff's Annal. d. Phys. und Chem., 2. Reihe, XXII, 1841, p. 41.

It is this feeling of the effacement of all human strife, and the oppressive consciousness of human insignificance in the face of the great forces of nature, which constitutes the religious element of the legend of the Deluge.

This element is so entirely in accordance with human nature that the tradition of this mighty phenomenon has readily found a place among the sacred myths of the most various peoples, and it is precisely this wide distribution of the *legend* which increases our difficulty in determining the actual extent of the *occurrence.*

In the great cycle of flood-legends traditions have also been included which treat of the origin of the sea; they belong properly to the group of cosmogonic myths and have no connexion with the Deluge. This is the case, among the myths of the Old World, with the story of the great rain by means of which, according to the seventh chapter of the Pehlevi Bundehesch, the waters of the earth were produced. An example of such a cosmogonic myth in the New World is found among the inhabitants of the Antilles in the deluge-story of the brothers who find a gourd bottle, from which after it is broken vast quantities of water pour forth. In the original form of this myth, as given by Petrus Martyr, there is no question of a deluge sent to punish and destroy; it is rather an explanation of the origin of the seas which filled up the dry hollows of the earth so that the mountains became islands[1].

Among many American tribes we meet with deluge-myths in which the precise details of the biblical account reappear, but as has been often pointed out, and in particular by Waitz, the influence of the missionaries is here unmistakable[2].

Another cycle of traditions is based on floods of seismic origin; these are found chiefly on the west coast of America, and on the oceanic islands as far as Fiji. We have already mentioned traditions of this kind when speaking of the oscillations of the ocean during great earthquakes. Réville has lately made a collection of oceanic flood-legends[3].

Putting all these traditions, which afford us no assistance in determining the extent of the Mesopotamian Deluge, on one side, there remain a number of accounts in the Old World which can be divided into several groups.

The first group, which is most closely related to the event we are considering, consists of the *Izdubar epic* and the fragment of *Berosus.*

[1] De orbe novo Petri Martyris ab Angleria Mediol. Proton. Decades; Compl. ap. Mich. d'Egnia. anno MDXXX, cap. ix, fol. 20.

[2] T. Waitz, Anthropologie der Naturvölker, 1862, III, p. 187. Attempts have even been made, with a great display of learning, to prove that all the deluge-myths originated in America. Noah was said to have been saved on Cuba, &c.; so e.g. Palaorama, Aus dem Nachlasse eines amerikanischen Naturforschers, 8vo, Erlangen, 1868, p. 192, et *passim.*

[3] A. Réville, Les religions des peuples non-civilisés, 8vo, 1883, tom. II, *passim.*

The account of Berosus mentions a circumstance to which there is no reference in the Izdubar epic, namely, the burial of the writings and their rediscovery at Sippara, the town of the sun. Eusebius writes: ... *Mandavisse, ut libros omnes, primos nimirum, medios et ultimos, terrae infossos in solis urbe Sipparis poneret.* It is difficult to say whether Berosus drew from another and more complete source than the author of the Izdubar epic, or whether we have to do with a later addition. The burial of documents in the foundations of temples and palaces was customary in Babylon from the most ancient times. As a newly found cylinder of Naboned (circ. 550 B.C.), lately described by Pinches, informs us, King Nebuchadnezzar (604–561) had looked in vain for old writings beneath the temple of the sun È-bara at Sippara. Some time later his successor, Naboned, found an extremely ancient cylinder at a depth of eighteen yards: 'The cylinder of Narâm-Sin, the son of Sargon, which for 3,200 years no king who lived before me had ever seen, Samas revealed to me the great lord at Ê-bara, the house, the seat of the joy of his heart.'

This takes us back to the year 3750 and places the ancient King Sargon I, who as we have mentioned above was exposed in a basket of reeds, approximately in the year 3800 B.C.[1].

The *second group* is represented by the two accounts of Genesis, the Jahvistic and the Elohistic, which are interwoven with each other. The close correspondence between the statements of this group and those of the first, from the warnings and the coating of the vessel with pitch to the setting up of the rainbow, is obvious. In numerical statements concerning the number of the animals and periods of time the two accounts differ from the Izdubar epic and also from each other. The Jahvistic account gives to the number seven the significance which it so often has in Assyrian narratives, including the Izdubar epic. Minor differences are also not wanting, for instance as regards the sending forth of the birds, and the statement that the Babylonian Noah, like Enoch in Gen. v. 24, is raised to the gods.

But the essential and characteristic difference lies in the fact that the whole description in Genesis has assumed that colouring which such a tradition must assume among an inland people[2]. A want of intimacy with the sea has often been pointed out. The pilot is absent, and the ship becomes a chest or coffer, an '*ark*.' There is naturally no mention at all of the divinities which personify the forces of nature; on the other hand, prominence is given in the Jahvistic portions to the personal

[1] T. G. Pinches, Some recent Discoveries, &c., Proc. Soc. Bibl. Arch., Nov. 7, 1882, pp. 6–12; Friedr. Delitzsch in Mürdter, Kurzgef. Gesch., pp. 273 et seq.; cf. also, among others, Taylor in J. Oppert, Expéd. scientif. Mesopot., I, p. 273.

[2] Lenormant, Orig., I, 2nd ed., p. 408, is the author of this acute observation.

activity of the divinity, as for example in the closing of the ark (Gen. vii. 16).

The council of the gods which precedes the flood, and Êa's conciliatory speech to Bêl after the catastrophe, by which feelings of mercy are again aroused, are here represented in a remarkable manner by two monologues of Jahveh's, which have long been a source of surprise to Bible commentators. Even Tischendorf's edition, which I have used for all other references, does not here give the original text. The reading of this edition is, viii. 21 *odoratusque est Dominus odorem suavitatis et ait,* whereas the true reading according to St. Jerome is: *et ait ad cor suum,* and in Luther's translation accordingly: *And the Lord smelled a sweet savour; and the Lord said in his heart, I will not again curse the ground any more*[1].

For us the account of Genesis is a *borrowed* description, but it undoubtedly refers to the same event.

We proceed to the *third* group, that of the *Egyptians*. It is here a matter of importance to determine whether an indigenous tradition of the Deluge exists, since the event on the Lower Euphrates occurred at a time when Egyptian civilization had long been flourishing, and the absence of indigenous accounts might be regarded as a proof that the catastrophe did not extend to the basin of the Mediterranean. And indeed there is little in Egyptian traditions which can be cited in this connexion, and that little departs so widely from the Chaldaean account that we may either regard the few points of resemblance as cases of accidental coincidence, or we must assume that a borrowed legend has suffered complete transformation under the influence of the priests.

The most detailed record of Egyptian mythology which has any bearing on the flood is the account of the destruction of men by the gods which covers the four walls of an isolated chamber in the sepulchre of Seti I (circ. 1350 B.C.) at Thebes.

According to Brugsch the chief contents are as follows[2]: Ra summons a council of the gods. Ra is wroth with men and complains that they speak against him. Their destruction is resolved on. The goddess Hathor accomplishes the work. She returns and is praised by Ra; the country is covered with blood as far as Herakleopolis.

[1] The ed. Tischendorf gives the following note to Gen. viii. 21 *et ait ad eum Mirum si hic transtulisset Hier. voces Hebraicas el-libbo, q.e. ad cor suum, in animo suo; Sept. διανοηθείς. Quare vel invitis Codd. Latinis Sixtini expunxerunt has voculas, nullo sententiae detrimento. Bellarminus earum loco malebat: ad se—animam viventem, animantem.* Dillmann, Genes., p. 141, thinks the writer is interpreting the thoughts of God.

[2] E. Naville, La destruction des hommes par les dieux, d'après une inscript. mytholog. du tombeau de Séti I à Thèbes, Trans. Bibl. Arch. Soc., 1876, IV, pp. 1–19; and in particular H. Brugsch, Die neue Weltordnung nach Vernichtung des sündigen Menschengeschlechtes, 8vo, Berlin, 1881, 41 pages and plates.

Ra calls all his messengers together and sends them to fill vessels with human blood and the fruit of the mandrake; 7,000 vessels of this beverage are prepared. Ra comes on the next morning to look at these vessels. And none of mankind had been destroyed who had gone upwards at the right time. Hereupon the majesty of Ra says: 'These are the good! Therefore will I protect men.'

Ra orders the liquid to be poured out of the vessels in the night, and the fields are covered with it. In the morning the goddess comes and sees the flooded fields; she rejoices and drinks of it; her soul is gladdened and she does not recognize men.

The further continuation of the myth—the birth of the priestesses, Ra's remorse, the reappearance of men, their reconciliation with Ra, the assignment of particular tasks to each of the divinities by Ra, and his own retirement—has no connexion whatever with the Deluge.

We have rather to inquire whether in the preceding portion such a connexion can be shown to exist. The council of the gods, the destruction of men, the subsequent mercy of the gods, even the promise not to repeat the disaster are present. But the catastrophe itself is of quite a different nature. Hathor fulfils the judgment by shedding of blood. Afterwards an inundation is mentioned, but this is evidently not to be regarded as a punishment.

It has, however, been observed that to the Egyptian people any inundation was so closely connected with the ideas of riches and life that it was necessary to alter the original tradition and to give Ra's judgment another form [1]. There is room for a difference of opinion on this point. From the whole description it is evident that *the great catastrophe did not occur in Egypt itself*, and that no recollection of such an event existed among the Egyptian people, even though Chaldaean reports may have come to the knowledge of the priests, traces of which survive in this myth. Brugsch denies all connexion with the Chaldaean myth.

The *fourth group* is composed of the *Hellenic-Syrian* accounts. In comparing these we must bear in mind that the shores of the Eastern Mediterranean, including the coast of Greece, have frequently been inundated by floods of seismic origin, both in ancient and modern times. A seismic agitation of the sea occurred in the year 479 B.C., when Artabazus was besieging the town of Potidaea, which cut off approach to the peninsula of Pallena, the most westerly point of Chalcidyce, an incident recalling the destruction of Pharaoh Menephtah. Herodotus relates how one day the besiegers observed a very considerable reflux of the sea which made the bay practicable, and how they were attempting to cross it in the direction of Pallena when they were surprised by the returning tide [2]. We

[1] Vigouroux; cf. Lenormant, Orig., I, p. 454.
[2] Herodotus, Urania, 129.

know of many other floods in Greece of the same kind but extending further inland; J. Schmidt enumerates several instances[1].

Under these circumstances it will not surprise us to find that traditions of repeated floods are to be met with in Greece, such, for instance, as those of Ogyges, of Deukalion, and of Dardanus; in addition to these, isolated traditions existed on the islands, as for example in Samothrace. It has been sought to establish a connexion between these Greek traditions, especially those referring to the flood of *Deukalion*, and the Chaldaean account, since they present certain features in common, such as the rescue by means of a floating chest, the presence of animals in the chest, and the sending forth of birds, particularly of a dove. But that which is specially characteristic of this group of traditions is its connexion with a ceremony which we have not yet mentioned. This is the Feast of the Dead which took place annually at Athens, on the 13th of the month Anthesterion, in memory of the flood of Deukalion. The libation of water, *Hydrophoria*, and the offering of honey and flour at the mouth of the chasm into which the waters of the flood of Deukalion are said to have poured, formed, according to Mommsen, part of this ceremony[2]. The chasm is situated outside the district of Leneum, but not far from it, close to the temple of Olympian Zeus.

In the book 'of the Syrian Goddess' which has, rightly or wrongly, been attributed to Lucian[3], a complete and remarkable account of the ceremony of the Hydrophoria is to be found in connexion with the description of the temple at *Hierapolis* on the Upper Euphrates.

The passages in question read as follows: 'It is generally said that Deukalion Sisythes[4] erected the temple, that Deukalion under whom the great flood took place. In Greece I also heard the legend which the Greeks tell of Deukalion, and the substance of which is as follows: "The wickedness of the first men is related; as a punishment," it continues, "a great misfortune fell upon them. The earth sent forth from her depths a great mass of water, vast falls of rain occurred, the rivers swelled, and the sea poured far and wide over the land, until everything was under water and every one perished except Deukalion, who alone survived . . ." for he had built a chest, and his family and pairs of all kinds of animals had entered it. The same chest contained them all as long as the water lasted. This is the story which the Greeks tell of Deukalion.

'The inhabitants of the town add to this a most remarkable tale, that in their country a great opening had arisen in the earth, and this had

[1] J. Schmidt, Studien über Erdbeben, 2. Aufl., 1879, pp. 138–165.

[2] A. Mommsen, Heortologie; Antiquarische Untersuchungen über die städtischen Feste der Athener, 8vo, 1864, p. 365.

[3] I give the translation by Theod. Fischer, Lucian's Werke, 8vo, 1867, III, pp. 229, 230.

[4] For the name Sisythes, Δευκαλίωνα τὸν Σισυθέα, not Σκυθέα, see Buttmann, Mythologus, 8vo, 1828, p. 192.

received all the water; but Deukalion after this had happened had erected altars, and beside the opening had built a temple in honour of Hera. I saw the opening: there is a very small one beneath the temple. Whether it was large in ancient times and has now become thus I do not know: the one I saw is very small. As a token, and in recollection of this story, they perform the following rite: twice a year water from the sea is brought into the temple. This is not carried by the priests only, but from all Syria and Arabia, nay even from beyond the Euphrates, many men come down to the sea, and they all carry water; at first they pour it out in the temple, whence it flows into the opening, and the little opening receives a great quantity of water. And with regard to this ceremony they say that Deukalion instituted it in the temple in remembrance of the disaster and of the mercy shown him. This is the ancient legend of the temple.'

A later passage relates that in the interior of the temple there stands an image of Hera, and also one of that god 'whom, although it is really Zeus, they call by another name.' 'Between these stands another golden statue . . . the Assyrians themselves call it the *sign*, but give it no particular name, and can tell nothing concerning its origin or its form. Some believe it to be Dionysos, others Deukalion, others again Semiramis. On its head is a golden dove, and for this reason it is thought to be Semiramis. Twice a year it is sent to the sea to fetch the water of which we have spoken.'

I have quoted this story in full, because it is a good example of the confusion and transference of myths. But we must not forget that Lucian lived in the second century of our era, and that the account is consequently much later than all those we have hitherto mentioned. At the very beginning the name Deukalion[1] is joined with the Hellenized Ḫasîs-Adra or Xisuthros, here Sisythes. Although the temple lies on the Upper Euphrates, the first part is expressly quoted as a legend of the Greeks, and yet this part corresponds in all essential features with the extremely ancient Chaldaean tradition. Even the three forms of inundation, from the earth, the heavens, and the sea, are mentioned.

In the second part the Hydrophoria brings the temple, which lies far inland, into connexion with the sea; we may see in this a Greek custom, although the dove on the head of the divinity, which is said to have journeyed twice a year to the sea, reminds us strongly of the Chaldaean accounts.

Thus the legend of the flood arrived by manifold routes in Greece, and thence apparently travelled back to the Upper Euphrates; the question now arises why absorptive fissures to carry off the water should be located precisely at Hierapolis. Such fissures are in fact occasionally formed during earthquakes; the draining of Lake Eulalie in the Mississippi valley,

[1] δευ-καλίων. Lenormant, Orig., II, 157, note.

which we have already referred to, was caused in this way, and Hierapolis (Mambedj) does actually lie in the great seismic zone of Antioch. But the true cause appears to be simpler. Rey has seen the ruin of the temple and published a plan of it; within the enclosure of the sanctuary, the remains of a fishpond mentioned in the ancient legend are still preserved, and Rey thinks it probable that the subterranean watercourses which exist beneath the town gave rise to a repetition of the story concerning the chasm which received the deluge, and also led to the erection of the temple[1].

It is not my intention to proceed further in the comparison of these different versions, which are derived wholly or in part from the Chaldaean catastrophe.

We have now become acquainted with four groups of legends. The first, consisting of the Izdubar epic and the fragments of Berosus, stands in the closest relationship to the event itself. The second, including the two accounts of Genesis, follows the first closely, and differs from it chiefly in the ignorance of navigation displayed. The third is the Egyptian group; we have only mentioned one account, but that the most important. The destruction of mankind is accomplished, not by a flood, but by the sanguinary Hathor; the flood only appears as a subordinate feature after the judgment. The connexion with the Chaldaean legend is very vague, and may be doubted altogether. The fourth group is the youngest and embraces the Hellenic-Syrian traditions; these include several floods, probably of seismic origin, which affected parts of Greece, or its entire coasts, and with which Chaldaean reminiscences and the ceremony of the Hydrophoria have been associated.

*From none of these accounts can it be shown that the catastrophe extended from Surippak to the basin of the Mediterranean.*

On the contrary, the antiquity of Egyptian civilization and the singular character of the myth in that country enable us to affirm with no small degree of certainty that the flood did not extend to the basin of the Mediterranean.

The sacred books of the *Hindoos*, the Rig-Veda, as well as the more recent writings, contain several stories of a great flood. Many circumstances point to the fact that Satyavrata in the Bhâgavata-Purâna, to whom the great flood is announced by Vishnu, and who is saved in virtue of his character as guardian of the sacred writings, is the same personality as Ḫasîs-Adra; we also meet here with the episode of the sacred writings which is found in Berosus, and with which we are already acquainted. But all these reminiscences of the Chaldaean tradition, recognizable in spite of their manifold transformations, although they show that the report of the great event had been carried hither, do not prove

[1] E. G. Rey, Rapport sur une mission scientif. dans le nord de la Syrie; Arch. d. miss. scientif., 2e sér., III, 1867, p. 351, pl. x.

that the flood itself extended so far. The fact that in the oldest of these, the Rig-Veda, the rescued Manu Vaivasvata fastens his ship to one of the summits of the Himalaya proves that the legend has been introduced from without, and has been localized in a completely unnatural manner.

The *Chinese* accounts appear to me to be of much greater importance.

The writings of the Chinese date from 3000 B.C., and are historical records. While free from anything supernatural, and making no claim to a higher revelation, they relate events for the most part in prosaic and definite language. The most important of these is the Schû-King, the book of historical documents; Legge's excellent editions have rendered it accessible to the European reader [1].

From the Schû we learn that in the reign of the Emperor Yâo a great and devastating flood covered China. The date of the Emperor Yâo's accession we will place with Legge in the year 2357 B.C.; J. B. Biot, basing his opinion on astronomical statements, considers this almost universally received figure to be correct. Yâo rules seventy years. He first summons Khwăn, and commands him to check the ravages caused by the flood.

In the Schû, in the third canon of Yâo, the following passage occurs: *The Ti says, Prince of the four mountains, destructive in their overflow are the waters of the inundation. Extending far and wide they surround the mountains and cover the great heights, threatening the heavens with their floods, so that the lower people are ill content and murmur! Where is there a man of ability whom I can command to put an end to this evil [2]?*

For nine years Khwăn struggles in vain; then Yü is summoned. Within a space of eight years he accomplishes great works; he clears the forests, he regulates the course of the rivers, dams them in and opens up their mouths, procures food for the population, and bringing order into the whole kingdom becomes a great benefactor.

The third part of the Schû, which consists of the books of Hsiâ, presents in the first book, under the title 'Yü-King,' or 'the tribute of Yü,' not only a detailed account of the works carried out by Yü, but a sketch of the geography of the country, in which rivers, mountains, lakes, and the resources of the provinces are enumerated. It is impossible to read this remarkable monument of an ancient administration without feeling the deepest respect for a nation whose records date from so early a period, and which during many thousands of years accords the highest praise to such deeds of peace and of public benefaction.

[1] James Legge, The Chinese Classics, III, pt. i, 8vo, Hongkong, 1865, and in Max Müller, The Sacred Books of the East, III, 8vo, Oxford, 1879.

[2] Legge, Sacred Books, III, p. 34; according to Chinese Classics, III, pt. i, p. 25, note, the commentator, Wu Ching, reads, instead of 'the lower people,' 'the people who dwell in the lowlands'; but Legge does not adopt this view.

The extensive knowledge of the country possessed by F. von Richthofen enabled him to determine from the Yü-King the course of the rivers four thousand years ago, and to show that the great plain has experienced but few changes since that time, with the exception of those caused by human agency, by alterations in the course of the Yellow River, and by the growth of the coast. Richthofen's researches have at the same time established with convincing thoroughness the correctness of the statements concerning the great works of Yü, the exactitude of which had been doubted by Biot, and even to a certain extent by Legge himself[1].

Missionaries have occasionally entertained the supposition that this flood is a reminiscence, though a very distant one, of the biblical Deluge; Bunsen has opposed this theory with incisive arguments. In more recent times there has been a tendency to ascribe the flood to the Ho, which has since that time caused such devastations that it is called 'the scourge of China.' Legge among others follows this view[2]; indeed nothing seems more natural than this explanation. Unfortunately, while Yü's travels and labours are described in great detail, the statements concerning the origin of the flood are most incomplete. We are only sure that sheets of water stood for a long time on the land, and that their disturbing effect on the conditions of daily life was considerable[3].

Our results may be summed up as follows:—

1. The event known as the *Deluge* took place in the region of the Lower Euphrates, and was connected with an extensive and devastating inundation of the Mesopotamian plain.

2. The chief cause was an earthquake of considerable violence in the region of the Persian Gulf, or to the south of it, which was preceded by several smaller concussions.

3. It is most probable that during the period of the most violent shocks a cyclone came from the south out of the Persian Gulf.

4. The traditions of other races do not justify us in asserting that the flood extended over the whole earth, or indeed beyond the lower course of the Euphrates and Tigris.

It is this occurrence, after remaining impressed on the memory of man for thousands of years, which has, under the influence of an entirely different hypothesis and by a strange concatenation of circumstances, passed from the sacred books of antiquity into the science of geology and given birth

[1] F. v. Richthofen, China, I, 1877, pp. 277–364, plates iv, v; in particular p. 335, note.

[2] Legge, Sacred Books, III, p. 18.

[3] In the representation of the state of affairs to be found in Mencius III. I. iv. 7 (Legge, Chinese Classics, II, pp. 126, 127), the passage does indeed occur: 'In the time of Yâo, *when the world was not yet in a state of order*, the rivers issuing from their beds caused a universal deluge,' &c. But this does not seem to me to correspond entirely with the much more trustworthy statements of Yü-kung.

to such terms as 'diluvium,' 'diluvial formation,' and 'diluvial deposits.' The flood was violent and destructive, but we have no proof that it was widely distributed. Its main features as they present themselves to the geologist are as follows:—

In the course of a seismic period of some duration the water of the Persian Gulf was repeatedly driven by earthquake-shocks over the plain at the mouths of the Euphrates. Warned by these floods, a prudent man, Ḫasîs-Adra, i. e. the god-fearing philosopher, builds a ship for the rescue of his family, and calks it with pitch, as is still the custom on the Euphrates. The movements of the earth increase; he flees with his family to the ship; the subterranean water bursts forth from the fissured plain; a great diminution in atmospheric pressure, indicated by fearful storm and rain, probably a true cyclone, approaches from the Persian Gulf, and accompanies the most violent manifestations of the seismic force. The sea sweeps in a devastating flood over the plain, raises the rescuing vessel, washes it far inland, and leaves it stranded on one of those Miocene foot-hills which bound the plain of the Tigris on the north and north-east below the confluence of the Little Zab.

# CHAPTER II

## SOME SEISMIC AREAS

Various branches of research. The north-eastern Alps. South Italy. The continent of Central America. Alleged spasmodic elevation of Chili. Rebounding of objects. Movement of submarine sediment. Valparaiso, 1822. Concepçion, 1835. Valdivia, 1837. Elevation of the land not proved.

There are probably few natural phenomena which have been made the subject of traditions and writings so numerous and various as have earthquakes. Accounts of them date, as the foregoing section has shown, from the earliest times, and now each year still brings its contribution of research. Unfortunately much of this investigation, though often of great merit, is unsystematic and too variously directed.

The majority of the records, especially those of ancient date, describe the premonitions of animals and the terror of men, enumerate the loss of life and property, and present vivid colouring, but vague outline.

Other works, perfect models of patient industry, seek to prove a periodicity in the recurrence of the phenomena. But there are two circumstances which from the outset render fruitless all attempts of this kind, however serious in intention they may be, as soon as comparatively long periods of time and a large number of earthquakes are involved. The first of these circumstances lies in the unequal value of the records, which far exceeds the limits admissible in work of this kind. The value of any particular tradition is directly dependent on the degree of civilization attained by mankind at the time, and on the existing state of knowledge of distant countries. Mallet drew up a little table in the year 1858 which shows how extraordinarily the number of observed earthquakes increases as we approach modern times, and this he rightly ascribed to an increasing completeness of the record; for the same reason the number of shocks in Europe attains a maximum in the nineteenth century[1]. It is only within the last few years, through the labours of E. Naumann[2] and J. Milne[3], that opportunity has been afforded us of studying the older records of earthquakes in Japan. The numerous accounts from the seventh, eighth, and more particularly the ninth century are in

[1] R. Mallet and J. W. Mallet, The Earthquake Catalogue; Rep. Brit. Assoc., 1858, pp. 28, 51.

[2] E. Naumann, Ueber Erdbeben und Vulcanausbrüche in Japan; aus den Mittheil. der deutsch. Gesellsch. f. Natur- und Völkerkunde Ost-Asiens, 15. Heft, 4to, Yokohama, 1878, pp. 4, 5.

[3] J. Milne, Notes on the great Earthquakes of Japan; Trans. Seismol. Soc. of Japan, 1881, III, pp. 96–102.

accordance with the high degree of culture which Japan had at that time already attained; on the other hand, there is a scarcity of information as regards the twelfth and sixteenth centuries, which Naumann ascribes to the political revolutions and the warlike enterprises of those periods. And for what a small portion of the earth's surface do we possess any older accounts whatever! While we search for traces of periodicity through thousands of data we find in them only the proof of our ignorance.

The second difficulty lies in the impossibility of arriving at a fixed rule in the selection of individual shocks for record in the course of any long persistent seismic phase. The cases in which the seismic movement exhausts itself for a long period by one violent shock, as in the last earthquake of Casa Micciola on Ischia, are among the rare exceptions. Much more frequent is the occurrence of a whole series of earthquakes, of varying intensity, accompanied or not by subterranean rumbling. Sometimes indeed the maximum intensity moves from place to place along a definite line; thus, when attempting to investigate the possibility of a connexion between concussions of the earth and the position of the sun and moon at the time, the conscientious observer is left in doubt as to which, among the numerous movements of the ground, some more and some less violent, he should record for comparison.

Another branch of investigation, making use of geometrical principles, attempts to determine, from the time of occurrence and direction of the movements at the surface, the exact depth and position of the point from which they proceed. But apart from the discrepancy which exists between the great exactness of the methods employed and the want of exactness in the observations on which the calculations must in most cases be based, the fundamental assumption is made that the focus from which the shocks proceed is a somewhat strictly circumscribed space in the interior of the earth. This assumption is, however, not proved. On the contrary it is much more probable that ruptures, or sudden displacements within the crust, take place simultaneously over extensive surfaces. In fact the data which point to a far-reaching synchronism of concussions are becoming increasingly numerous. Whitney thinks there is conclusive evidence to show that in the violent earthquake of Owen's Valley, on the east side of the Sierra Nevada in California, which took place on March 26, 1872, the chief shock was felt simultaneously over the whole region between the 34th and 38th degrees of latitude parallel to the direction of the Sierra; while in a direction approximately at right angles to this the undulation reached the middle of the Valley of San Joaquin in 2–3 minutes, and that of the Sacramento Valley in 3–4 minutes, and the coast between San Francisco and Los Angelos in from 4 to 5 minutes[1].

[1] J. D. Whitney, The Owen's Valley Earthquake of March 26, 1872; Overland Monthly for Aug. and Sept., 1872, p. 273.

In the earthquake which occurred on March 2, 1878, over the whole of the Upper Punjâb and the neighbouring districts, from Banun, Kohât, Peshâwar, and Râwalpindi to Lahore and Ferozpur, and even beyond Simla, Wynne was unable to distinguish appreciable differences in the time of the shocks, although the distance between the extreme points of observation measured 732 kilometers in a straight line, and the structure of the ground over this large region is very varied[1].

In the same way Heim has proved the simultaneous manifestation of the shock over a great distance in the case of several Alpine earthquakes.

The earthquake of July 4, 1880, extended from the valley of the Po right across the Alps into the Schwarzwald. The major axis of the district affected measured about 305 kilometers, and ran from north to south between Vercelli and Lenzkirch; a line at right angles to this from Genoa or Annecy to Poschiavo or Chur measured 230 kilometers. The following table gives the times at which the arrival of the shock was observed:—

| | | | |
|---|---|---|---|
| Zürich | 9 *h.* 20′ | San Bernardino | 9 *h.* 19′ 30″ |
| Wattwyl (Toggenburg) | 9 *h.* 19′ 40″ | Brieg (Valais) | 9 *h.* 19′ 40″ |
| Einsiedeln | 9 *h.* 20′ 30″ | St. Leonard (nr. Sitten) (Valais) | 9 *h.* 20′ 35″ |
| Andermatt | 9 *h.* 20′ 47″ | Geneva | 9 *h.* 20′ 4″ |
| Airolo | 9 *h.* 21′ 3″ | Lugano | 9 *h.* 19′ |
| Faido (Tessin) | 9 *h.* 20′ 3″ | | |

Heim concludes from this that the cause of the earthquake of July 4, 1880, could only lie in the synchronous and intermittent movement of a very extensive fragment of the earth's crust, not in a local and violent impulse[2].

Thus three observers in different parts of the world have arrived independently of each other at the same result.

The increased attention which has of late been directed to these phenomena, the growth of education among the people, and the development of the press, which has made observation possible over extensive areas, have been followed by the discovery that in Central Europe seismic movements of the earth are infinitely more frequent than has previously been supposed. Since the systematic organization of observations in Switzerland, Heim has shown that no less than sixty-nine earthquakes were experienced in the Swiss Alps between November, 1879, and the end of 1880, that is during fourteen months. Yet more numerous are the earthquakes in other parts of the world, especially in Japan, where Milne

[1] A. B. Wynne, Notes on the Earthquake in the Punjab of March 2, 1878; Journ. Asiat. Soc., Bengal, 1878, XLVII, part 2, pp. 131–140.

[2] A. Heim, Die schweizerischen Erdbeben vom November 1879 bis Ende 1880; nach den von der Erdbeben-Commission gesammelten Berichten, 4to, Bern, 1881, pp. 18–20.

counted thirty-six distinct earthquakes, which affected the region extending from Tokio to Kamaishi between October 19 and December 31, 1881, that is in seventy-three days[1]. No doubt a similar state of disturbance prevails in other volcanic regions. Moreover we are now considering not transitory phases of exceptional seismic activity, but, so far as we are able to judge, of a fairly normal state of affairs: and only such concussions are taken into account as can be perceived without special instruments. Some observers indeed even go so far as to maintain that in many regions the apparent repose of the earth's crust is deceptive, the result merely of defective observation; with sufficiently sensitive instruments it can be shown that these regions are in a condition of constant movement[2]. Others again have even maintained that the effect of earthquakes in South America could be recognized, through the whole mass of the planet, in the oscillations of the instruments in the Observatory of Pulkowa[3].

In this, as in other branches of research, an increase of knowledge can only be expected from as close an observation as possible of the phenomenon itself. Shocks of moderate intensity, causing damage and alarm only to a comparatively small degree, or affecting only a very limited area, may furnish results just as valuable to science as the most terrible catastrophes. It is necessary for their study that a sufficient number of competent observers should be distributed throughout the country affected, the structure of which must be known in its main features. It is further necessary to compare as great a number of earthquakes as possible within a limited area, since the difference in the nature of the movements is not small, and the sources of error are many. It is therefore a matter for well-considered and carefully organized work.

Fortunately work of this kind has been in progress in several places for some years. The Swiss Earthquake Commission gives promise of important contributions, judging by the reports already published. In the eastern Alps, in Italy, and in Japan a lively interest has been awakened in these researches; and in a few years we may certainly expect to be in a much better position to discuss the question of the connexion between the structure of the earth's crust and its movements than we are at present, and with a greater degree of certainty than can attend my attempt in the following chapters.

Some definite results have, however, already been obtained. As examples I have chosen four chief seismic areas, each distinct in type.

The first is the region of the *north-eastern Alps*; no volcano is present. Although investigations have been in progress but a few years, yet the results

[1] J. Milne, The Distribution of Seismic Activity in Japan; Trans. Seismol. Soc. of Japan, 1882, IV, p. 30.

[2] Rossi, Meteorologia Endogena, 8vo, vol. II, 1882, Microsismologia.

[3] Nyrèn, Bull. Acad. Pétersb., 1877, XXIV, p. 567.

are so singularly concordant as to render it possible to arrive at definite conclusions.

The second example is *South Italy.* Volcanos are present, but in this limited area they are not arranged in lines; their connexion with the earthquakes of the district may nevertheless be recognized.

The third example is the *continent of Central America.* Earthquakes are frequent, but have been little studied. The peculiar arrangement of the volcanos, in default of information as to the movements, is sufficient however to indicate the main lines of disturbance.

The fourth example bears upon certain events which have taken place on the *west coast of South America.* Under this head a particular theory, maintained by many eminent authorities, to the effect that certain earthquakes were accompanied by a spasmodic elevation of the land, will be examined.

## A. *The North-eastern Alps.*

A steep and almost unbroken scarp, forming the western border of the Bavarian Forest, runs towards Passau; there it crosses the Danube to the south, appears again on the north side below Linz, once more crosses over between Grein and Krems, to extend on this side nearly as far as St. Pölten, whence it turns finally to the north-east, and proceeds past Maissau and Znaim, towards Brünn. This is the sharply defined boundary of the great mass of Bohemia. Above it lie the moist and wooded tablelands of the northern part of Upper Austria, and the Waldviertel of Lower Austria, the Mannhart, and the north-west of Moravia; they form the outer region of the plateau, which is continued through a great part of southern Bohemia. These high-lying regions consist, almost exclusively, of granite, gneiss, and ancient schist.

At the foot of the scarp lies the plain which separates the Bohemian mass from the Alps; the Danube flows through it except where it has preferred to excavate its bed in the rocky masses jutting out to the south from the old plateau. That part of the plain which lies in Bavaria is broad; it narrows down between Ybbs and St. Pölten, widening out again as it extends far into the north-east.

To the north of Brünn Devonian rocks extend from the Sudetes to the outer margin of the Bohemian mass; between Leipnik and Weisskirchen they meet the outer zones of the Carpathians.

The outer margin of the Alps and the Carpathians describes a very constant curve; it is interrupted near Salzburg, and again for a long interval between the Bisamberg, near Vienna, and the Marsgebirge in Moravia—in this interval the outer zone is only represented by an isolated remnant here and there. The curve runs from Laufen past Steyer, crosses

the Danube to the west of Klosterneuburg, and is continued to the east from Nikolsburg towards Kremsier as far as the already mentioned point of contact with the Devonian near Leipnik and Weisskirchen. The arc then returns past Neutitschein and Kenty towards Wieliczka, where it is faced by the heights of Cracow.

This border, where it is not interrupted by later subsidence, forms just as striking a feature in the country as the edge of the plateau. Its slope is not so steep as that of the ancient Bohemian mass; it is more frequently intersected by transverse valleys, and is even more thickly wooded: within it the mountains rise step by step to far more considerable heights, and

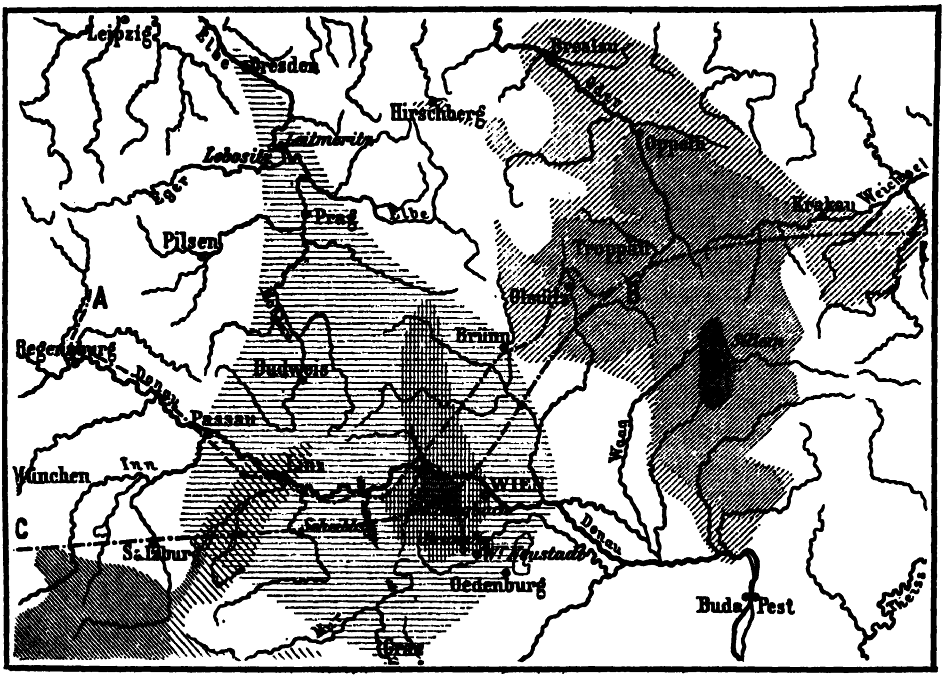



FIG. 8. *Recent earthquakes in the north-east of the Alps and west of the Carpathians*
A, B, Southern edge of the Bohemian mass and of the southern part of the Sudetes; C, B, D, North border of the Alps and the Carpathians; B, Point of contact near Weisskirchen.

in forms incomparably more varied than those of the monotonous plateau of Bohemia. The contrast between these two mountain systems, both in their structure and in their stratified sequence, is extremely sharp, and the narrow plain, which separates them, doubtless conceals one of the most remarkable areas of disturbance in the continent of Europe.

The more violent earthquakes of the outer border of the Alps, those at least which have been studied in modern times, exhibit a peculiar tendency to extend across this dividing zone into the plateau on the other side.

The *earthquake of Sillein* on January 15, 1858, attained its maximum force in the upper valley of the Waag, in an irregular elliptical area stretching approximately north to south, into which the granite mass of Mount Minčow projects. The area of concussion, gradually narrowing away to the south, extended as far as Gran on the Danube. The shocks were felt to the east as far as Tarnow, and to the west as far as Brünn; they extended in an irregular manner through some parts of the Riesengebirge and a great part of the Sudetes, and in the north they reached Trebnitz to the north of Breslau[1].

Although this shock had its seat in the interior of the Carpathians, the concussion not only propagated itself across the opposing mountain chain, over the plain and into the mountains on the other side, namely, the Riesengebirge and the Sudetes; but a considerable part of the area affected lay outside the Carpathians, and its major axis ran perpendicular to the strike of the chain.

The *earthquake of Neulengbach* in Lower Austria, on January 3, 1873, was felt most violently in the vicinity of the outer border of the Alps. It attained its maximum in the neighbourhood of Hummelhof near Neulengbach, quite close to the outer edge of the Flysch zone. The outline of the area, within which the vertical movements and the more serious concussions occurred, has the form of a cross. The two arms lie between Königstetten and Pyhra, near the edge of the Flysch zone; at right angles to these one branch longer than the arms extends as far as Hornstein into the Alps, that is to the south-east, and the other, much longer still, proceeds in the opposite direction or to the north-west, crosses the Danube near Preuwitz, and runs up the valley of the Kamp in the granite region as far as Wildberg near Messern. The extreme limit of the shaken area does not extend much beyond Hornstein in the direction of the Alps, but it stretches much further to the north-west, as far as Meseritch and Trebitsch in Moravia.

Here, again, the axis of the area of concussion is perpendicular to the strike of the chain, but the greater part of the area lies outside the Alps, and extends as a long tongue into the granite plateau. This case is typical of those earthquakes which, proceeding from the border of the Alps, are propagated into the confronting mass of Bohemia.

On June 12, 1874, another earthquake occurred in the same locality, but with less intensity; this time the shock was transmitted to the north-west as far as Raabs, and to the south-east as far as Klausen-Leopoldsdorf; thus

[1] L. H. Jeitteles, Bericht üb. d. Erdbeben am 15. Januar 1858 in den Karpathen und Sudeten, Sitzungsber. k. Akad. Wiss. Wien, XXXV, 1858, pp. 511–592 und Karte; J. Schmidt, Untersuchungen üb. d. Erdbeben vom 15. Januar 1858, Mittheil. geogr. Gesellsch. Wien, II, pp. 131–203 und Karte; A. Kornhuber, Erdbeben vom 15. Januar 1858, besonders rücksichtlich seiner Verbreitung in Ungarn, Ber. des Vereins f. Naturk. in Pressburg, 1858.

again penetrating much further into the granite on the other side of the plain than into the Alps, where it did not even pass beyond the Flysch zone.

But it appears that in earlier times also this same region has been repeatedly convulsed by shocks which have followed the same line of propagation, the point of seismic maximum lying sometimes close to the outer border of the Alps near Lengbach, and sometimes within the Alps near Brünn, not far from Wiener-Neustadt, at the point of intersection of this seismic line with the line of thermal springs, which in its course from Neustadt to near Vienna marks the limit of the Alpine subsidence. But the seismic line has never yet been traced further south than this area of subsidence, which is covered with Tertiary deposits and flat cones of débris which have been pushed down from the Alps. On the other hand the earthquakes which have occurred on this line have always been propagated to the north-west into the mass of Bohemia, over distances greater or less according to the violence of the shocks, but often passing beyond Prague. In the direction of the Alps they travel over much smaller distances, the disturbance frequently ending in the more recent deposits which fill up the sunken area near Neustadt, where they manifest themselves by violent local shocks which devastate the neighbouring towns and villages.

The earthquake of June 29, 1590, on this line reached as far as Iglau. The particularly violent earthquake of September 15, 1590, the most violent which has occurred in the Alps since the existence of historical records, attained its maximum force in the neighbourhood of Neulengbach, passed Iglau, continued onwards with great intensity as far as Prague, and was distinctly felt even in Leitmeritz. On February 27, 1768, the principal shock occurred near Brünn on the line of thermal springs, causing damage in Neustadt; it travelled along the previously mentioned seismic line to the north-west, and was felt beyond Iglau.

These examples may suffice to give some idea of the importance and fixity of this seismic line, and of the constancy in character of the earthquakes originating upon it. It is known as the *Kamp line*[1].

When, on March 14, 1837, a violent shock occurred on the Kamp line in *Mürzzuschlag and on the Semmering*, on the south edge of the sunken area of Neustadt, the behaviour of the shaken region remained the same. Towards the south the movement was not perceptible further than Bruck on the Mur, while to the north it was observed beyond Prague as far as Alt-Bunzlau[2].

On July 17, 1876, a fairly violent earthquake occurred further to the

[1] Die Erdbeben Nieder-Oesterreichs; Denkschr. k. Akad. Wiss. Wien, 1873, XXXIII, pp. 1-38, and maps.

[2] The chief source of information for this earthquake is a note in Poggendorff's Annal. Phys. Chem. 1837, 42. Bd., pp. 685-690.

west in the neighbourhood of *Scheibbs*, in Lower Austria; the seismic maximum lay, as in the earthquake of Lengbach, close to the outer border of the Alps, and the concussion was very violent over a small and narrow area, which extended from Scheibbs to the south-south-east as far as Kindberg in Styria, and to the north-north-west beyond Scheibbs as far as Persenberg, on the border of the Bohemian mass. The seismic area as a whole presented the form of a pear or bottle; it extended in the Alps only as far as Gratz, to the east as far as Pressburg, to the west up to the Mondsee and Passau, while to the north it gradually narrowed away till it reached Dresden. Bells were set ringing even in Lobositz on the Elbe [1].

Thus this earthquake also occurred in a direction perpendicular to the strike of the Alps, and it travelled through the whole breadth of the Bohemian mass as far as Saxony.

In all these examples, that is, in the case of all earthquakes which have had their origin in this part of the Alpine system, and have extended over an area with which we are exactly acquainted, the concussion has taken place, with the exception of some very secondary and locally limited shocks, at right angles to the strike of the mountains. It has always appeared to follow a more or less sharply defined line; concussions of varying intensity have repeatedly occurred on the same line, and the shock has always been transmitted further to the north, into the opposing mass of the ancient plateau, than to the south, into the folding mountain chain from which it proceeded.

The reason of this coincidence is not yet known; but I consider we are justified in maintaining that all these earthquakes have a common cause, and that the force which manifests itself in them is always present, but only occasionally obtains expression.

If we proceed further into the interior of the Alps we meet with conditions which are extraordinarily complicated. The *earthquake of Belluno* on June 29, 1873, although it originated in the southern border of the Alps, was also transmitted across their whole breadth, and passing Linz and Freistadt even entered the Archaean plateau [2].

R. Hoernes has endeavoured to establish the existence of a seismic zone at the south foot of the eastern Alps, extending from Lake Garda to beyond Fiume; this would be a peripheral seismic line, and from it a number of transverse seismic lines are supposed to extend into the Alps [3]. H. Hoefer, from a comparative study of the earthquakes of

[1] According to a collection of as yet unpublished accounts.

[2] Bittner, Beitr. zur Kenntniss des Erdbebens von Belluno vom 29. Juni 1873; Sitzungsber. k. Akad. Wiss. Wien, 1874, Bd. 69, p. 6.

[3] R. Hoernes, Erdbebenstudien; Jahrb. geol. Reichsanst. 1878, XXVIII, pp. 387–448, and map.

Carinthia, has been led to suppose the existence of a network of long lines, some of which follow the trend of the chain [1]. But it is precisely this segment of the Alps which, as we shall see later, is distinguished by a very complicated structure, and it will be the task of further investigations to determine which of these two conceptions makes a nearer approach to the truth.

There is a general agreement among recent observers that, in the case of transversal earthquakes, a displacement of one mountain segment against another takes place in a horizontal direction and by jerks. The nature of the movement points to steeply inclined fractures, standing perpendicular to the strike of the mountains; a form of Alpine dislocation, which later on will receive the name of 'flaw' (*Blatt*). In the south Hoernes has attempted to trace a direct connexion between the earthquake of Belluno and visible faces of dislocation of this kind [2]. Bittner has pointed out the parallelism between the numerous flaw faces of the north-eastern end of the Alps, which strike N. 15° W., and the Kamp line [3]. But we need not, therefore, conclude that these flaws are continued in the Archaean mass on the other side: and if not, the remarkable elongation of the seismic area to the north would then be only a phenomenon of propagation, marking the direction of the shocks which proceed from *within the Alps.*

### B. *South Italy.*

Looking from the volcanos of Lipari towards the mainland, or to the north coast of Sicily, masses of primitive rock with scarped faces are seen on every side. Gneiss or granite form the greater part of these rocks, and the succeeding zones of schist and younger rocks up to the Flysch occur on that side of the range which faces away from the Lipari Isles.

Towards the north-east, Monte Cocuzzo turns its steep declivity to the Tyrrhenian Sea; it is crowned by a remnant of transgressive limestone; towards the interior the longitudinal valley of Crati separates Cocuzzo from the great mountain core of the Sila.—To the east rise the gneiss-formed heights of Cape Vaticano and the granite cliffs of Scylla, both of them fragments faulted down from the Aspromonte, which rises abruptly above them, and on its eastern side, looking towards the Ionian Sea, is mantled with more recent deposits.—Finally on the south, along the Sicilian coast, the borders of the ancient Peloritan mass face the Lipari Isles; its oldest granites are exposed in the north-eastern part of the island, while on the

[1] H. Hoefer, Die Erdbeben Kärntens und deren Stosslinien; Denkschr. k. Akad. Wiss. Wien, 1880, Bd. 42, 2. Abth. pp. 1–90, and maps.

[2] R. Hoernes, Das Erdbeben von Belluno am 29. Juni 1873; Mittheil. d. naturw. Vereins f. Steiermark, 1877, and in other places.

[3] R. Bittner, Die geol. Verhältnisse von Hernstein in Niederösterreich. Mit Unterst. Sr. k. Hoh. des Erzh. Leopold herausgegeben von M. A. Becker, I, 4to, 1882, p. 308.

opposite side, on the slopes turned towards Aetna, the younger zones of Aspromonte are continued with a change of direction.

Thus Aspromonte, the hills of Vaticano, Scylla, and the Peloritan mountains represent the fragments of a once continuous mountain chain, now cut through by the Straits of Messina. Its chief marginal fracture, situated on the west side of Aspromonte, faces the Lipari Islands [1].

This fracture was the path along which seismic activity made its appearance for some months in the year 1783, with repeated displacement of the epicentre. This series of disturbances appears to have commenced,

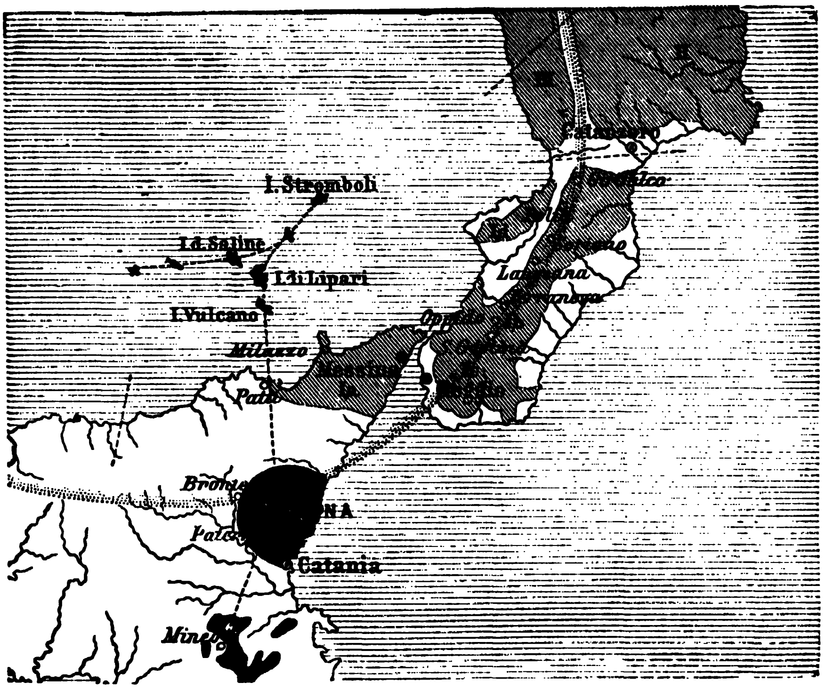



FIG. 4. *The peripheral line of the Lipari Islands.*

The volcanic rocks are indicated by dark, the granite, gneiss, and schist by lighter hatching.

I. The fragments of the mass of Aspromonte (I a, Peloritan mountains; I b and I c, Aspromonte, with a fragment of Scylla lying to the west; I d, fragment of the Vaticano).

II. Mass of the Sila.

III. Mass of the Cocuzzo (faulted down towards the sea).

[1] Die Erdbeben des südlichen Italien, Denkschr. k. Akad. Wiss. Wien, XXXIV, 1875, pp. 1–32. An important supplement to the sketch of the geological structure given here is to be found in L. Burgerstein and F. Noë, Geolog. Beobachtungen im südlichen Calabrien, Sitzungsber. k. Akad. Wiss. Wien, 1880, LXXXI, Pt. i, p. 154, with map and section; in the detailed Monograph on the younger deposits by G. Seguenza, Le formazioni terziarie nella prov. di Reggio, Atti della R. Accad. dei Lincei, 3. ser., VI, 1880; and in E. Cortese, Sulla formaz. dello Stretto di Messina, Boll. com. geol., 1882, XIII, pp. 4–39, Tav. i, ii.

as early as 1780, with an eruption of Aetna, which was followed by violent local shocks near Ali and Fiumi di Niso, on the coast of Sicily; then an eruption of Vulcano took place, and, on February 5, 1783, the first considerable shock occurred along the fracture of Aspromonte, near Oppido and Santa Cristina, when the younger Tertiary deposits were severed from the marginal fracture by a long deep cleft. The concussion was propagated to the south, west, and north, but only a short distance to the east, that is, not far across the marginal fracture. Within a few weeks there was an unmistakable change in the position of the centre, the epicentre travelling past Soriano and Polia as far as Girifalco, near the northern extremity of the fracture, and then returning to Radicena, near Oppido, that is, close to its point of departure. With the exception of some extensive landslips in the port of Messina, no permanent alteration took place in the sea-coast.

A comparison with other concussions which have occurred on the southern shore of the Tyrrhenian Sea shows us that the line of 1783 forms part of a great curve, closely approximating to a circular arc, which surrounds the Lipari Isles on the east and south, and is characterized by numerous earthquakes. The arc runs east from Monte Cocuzzo, through the valley of Crati, passing through Luzzi, near Bisignano, Cosenza, Donnici, and San Stefano, near Rogliano, to Girifalco, thence along the dislocation of Aspromonte through Pezzoni, Soriano, Terranova, Oppido, and Santa Cristina, and finally on the other side of the Straits it passes to the south of the Peloritan mass through Ali to Aetna, whence it is continued through Bronte and Nicosia to the Montes Madonie.

In addition to this peripheral line, a number of other seismic lines are known in this region, which radiate from the Lipari Isles, and along which the concussions are, so far as has been observed, directed from the islands outwards; some of these lines cross the peripheral line and extend beyond it, others, especially in the neighbourhood of Aspromonte, appear to end on it. They run as follows:—to the north-east, from Amantea, across the peripheral line and the whole peninsula as far as Rossano on the east coast; to the east-north-east, into the Gulf of Santa Eufemia, and past Catanzaro to the east coast; to the south, from Vulcano to Aetna, and from there south-south-west to Mineo, and then far to the south-west past Palermo towards Favignana.

The arc has a radius of about 90–100 kilometers; Cocuzzo, Cape Vaticano, Scylla, and the Peloritan mountains lie within it, Sila and Aspromonte without it. The radial lines converge towards the Lipari Isles. F. Hoffmann pointed out, as early as 1832[1], and the fact has lately

[1] F. Hoffmann, Ueber die geognostische Beschaffenheit der Liparischen Inseln, Schreiben an Herrn L. von Buch; Poggendorf's Annal. Phys. Chem., 1832, XXVI, pp. 81-88, Taf. iv.

been confirmed by Judd[1], that within the Lipari Isles, south of Stromboli, at a place which may be regarded as the approximate centre of the peripheral line, there lies a group of small islands and cliffs, the structure of which differs from that of the remaining islands. For while on the others the centres of eruption are marked by craters of larger or smaller size, this whole group consists solely of the ruins of one mighty crater, which Hoffmann describes as the central crater of the Lipari Isles.

From this irregular ring-shaped group, consisting of the cliffs and islands of Panaria, Basiluzzo, Dattilo, Lisca bianca with the submarine fumarole, Bottaro, Panarella, Formiche, and Lisca nera, there radiate, according to Hoffmann and Judd, three lines on which lie the eruptive centres of the Lipari Isles. The first of these runs to the west-south-west past Salina, Filicuri, and Alicuri; the second starts to the south-south-west to Lipari, but then turns to the south-east through Vulcano to the solfatara on Cape Calava; while the third goes to the north-north-east, passing through Stromboli.

If we compare these lines, the course of which may be seen on Hoffmann's map, with the network of lines determined solely from the evidence of seismic activity, we shall find it difficult to resist the conclusion that these volcanic radial lines stand in some connexion with the seismic radial lines. Several trustworthy observers have already perceived a correspondence between an increase in activity of Stromboli and earthquake shocks in Calabria; it was noticed by A. Kircher in the year 1638[2], by Conte Ippolito[3], Grimaldi[4], and most of those who experienced the great earthquake of 1783. Similarly, Ferrara, by means of numerous examples, has endeavoured to prove the existence of a connexion between eruptions in the Lipari Isles and concussions on the north coast of Sicily[5].

We are thus led to the conclusion that within a space bounded by the peripheral line of 1783, *the crust of the earth has sunk down in the form of a dish, and thus radial fractures have been produced, which converge to the Lipari Isles.* These converging lines are beset with volcanos near their centre of origin. Any disturbance in the equilibrium of the several

[1] J. W. Judd, Contributions to the Study of Volcanos, Geol. Mag. Jan. 1875, particularly p. 4 and p. 214, and the little map on p. 7. Cortese also has recently given the lines of fracture as follows:—(1) East to west: Alicuri, Filicuri Saline; (2) North-east to south-west: Stromboli, Panaria, north part of Lipari; (3) North to south: Lipari, Vulcano, Vulcanello. Cortese, Sulla cost. geol. dell' Isola di Lipari; Boll. com. geol., 1881, 2. ser., II, p. 502.

[2] A. Kircheri, Mundus subterraneus, Praef. and p. 240.

[3] Cte. Ippolito in Hamilton's account, Phil. Trans., 1783, p. 213, et seq.

[4] Grimaldi, Descrizione de' tremuoti accad. nelle Calabrie nel 1783, 8vo, Naples, 1784, p. 46.

[5] Ferrara, Mem. sopra i tremuoti della Sicilia in Marzo 1823, 8vo, Palermo, 1823, in particular pp. 23, 32, et seq.

fragments of the crust gives rise to increased volcanic activity on the islands, and to earthquakes on the mainland or in Sicily.

If this process of subsidence should pursue its course, then the low gneissose hills of Cape Vaticano, the granite mountains of Scylla, and a large part of the Peloritan mountains, with the Madonie, will sink beneath the Tyrrhenian Sea, which will then, after the complete demolition of the Tertiary deposits now lying in front of it, wash against the peripheral fracture on the west side of Aspromonte, as it now does on the west side of Cocuzzo. The Straits of Messina will be broader, and all that will be left of the curve described by the younger zones of the Apennines, which may at present still be recognized from its remains, will be at most an isolated fragment rising between Ali and Taormina, forming the eastern promontory of a greatly diminished Trinacria, and presenting to the geologist an almost insoluble problem.

It will be seen in a later chapter that the separation of Sicily from North Africa may be attributed to similar processes. For the present we may draw the following inferences from these observations: that radial fissures play an important part in the subsidence of the western side of the Apennines, and that the cause of the numerous centres of eruption in the Lipari Isles is probably to be found in the convergence of these radial lines and in their mutual intersection. The region of the Phlegraean fields may perhaps be similarly constituted; and the tendency to displacement of the eruptive centres might be attributed to the greater mobility of the thin ends of the orographic quoins. The great isolated and persistent volcanos lie nearer to the marginal cleft, perhaps at the points where this is intersected by the radial fissures [1].

### C. *The continent of Central America.*

The volcanos of Central America are equally independent of the volcanos of Quito, of the crescentic arc of volcanos of the Lesser Antilles, and of the chain of Mexican volcanos which extend across the continent from west to east. They begin with the volcano of Chiriqui in lat. 8° 48′ N., pursue a north-westerly course as far as the Bay of Fonseca, and from there

[1] I have purposely omitted to quote the wonderful system of radial fissures which Rossi has described as proceeding from the Albanian mountains. I willingly subscribe in all essential points to the results obtained by this diligent observer as to the movement on fissures, as well as to certain observations on faults, and in particular to the proof produced by Ponzi of a fault in the Tiber valley situated in Rome itself. But after Ponzi's work it seems to me hardly feasible to return to Breislak's opinion that a volcano once stood on the site of the forum; still less would it be possible to distinguish with any degree of certainty lines supposed to lie so near to one another, by means of earthquakes, and especially not from a single concussion, affecting all the supposed lines simultaneously. The radial lines in Calabria are widely separated from one another, and have acted as independent lines of seismic shock at very different times. M. St. de Rossi, Meteor. Endog., I, pp. 200–238, Atti Accad. Lincei, 1873.

extend along a line somewhat more to the west-north-west, as far as Socomusco in Mexico.

We might therefore, perhaps, speak of two great chains, which meet at an obtuse angle in the Bay of Fonseca, but both have this remarkable fact in common that the volcanos rising from them, which are often of gigantic dimensions, frequently stand on easily recognizable transverse fractures. Sometimes an independent transverse line, some miles in length, has been formed, as in the chain of Chiquimula, in eastern Guatemala; at others again the displacement of the eruptive centre, which takes place at right angles to the chief line, is only indicated by the structure of the summit. This tendency to abandon the old eruptive channel is universal.

The chief line, particularly to the west of the Bay of Fonseca, follows the Pacific coast very closely; the transverse lines, on which the eruptive activity is displaced, are more or less perpendicular to it, and in almost every case it is the crater lying farthest to the south-west, i. e. nearest to the Pacific coast, which alone is active.

*The displacement thus takes place along longer or shorter transverse fractures and is directed towards the Pacific Ocean.* This is the more remarkable since it stands in no perceptible relation to the structure of those fragments of older mountains which exist in this region.

The most southerly centre of eruption, Mount Chiriqui, is succeeded towards the north-west by Mount Robalo, which does not as yet seem to have been closely examined. Here the main line of volcanos meets the Cordillera of Talamanca, which is composed of granite and syenite. Vertical and folded strata of Miocene age border the granite mountains to the north, and on the line of volcanos Pico Blanco rises to a height of 3,620 meters. This was long held to be a volcano, until Gabb ascended it and showed that its summit consists of a dyke of ancient porphyry rising out of the weathered granite[1].

The line of volcanos is not, however, diverted by the line of granite mountains; on the contrary volcanos such as Monte Lyon, and probably also the Ujum, are seated on the latter[2]; these are followed by the volcanos Irazu and Turrialba, Zurqui, Barba, and Poas.

The summit of Turrialba is described by Seebach as a ridge running from the east-north-east to the west-south-west, and thus perpendicular to the main volcanic line. It may be regarded as a type of those volcanos

[1] W. M. Gabb, Notes on Costa Rica Geology; Am. Journ. Sc. Arts, 1875, 3rd ser., IX, pp. 198–204, 320. Humboldt regarded the Pico Blanco as an 'unopened trachyte cone' (Kosmos, iv, 1858, p. 307), M. Wagner as a volcano (Naturw. Reisen im tropischen Amerika, 8vo, 1870, p. 323 et seq.).

[2] The relative position of Lyon and Ujum to the Pico Blanco may be clearly seen on the map in Petermann's geogr. Mittheil., 1877, XXIII, Taf. 18; for the more northerly district as far as Lake Nicaragua the map by Frantzius may be consulted, op. cit. 1869, XV, Taf. 5.

which shift their centre of eruption in a definite direction. The most recent crater, and at the same time the least elevated, i. e. if our comparisons are made from the height of the crater floor, lies to the west-south-west. It is still active[1]. Gabb gives the height as 3,461 meters.

'In the Poas,' says Seebach, 'I have found the most complicated volcano, of which I have ever heard: a twin volcano with axes of activity advancing lineally. . . . It is a remarkable feature, in the case of all these volcanos, that when a main line of direction is present it runs obliquely to the direction of the chain. The only exceptions are Zurqui, Rincon, and Orosí[2].'

The line of volcanos now reaches the coast of the Pacific Ocean and runs along it. Among the more important volcanos are Cuipilapa (Miravalles), Rincon de la Vieja, Orosí, Omotepec (which rises from the midst of Lake Nicaragua), Zupateca, and others, then Mombaco, the often-described group of Masaya and Nindiri, and finally Mombotombo. In the plain of Leon, which follows, a large number of volcanos occur. From Mombotombo to Viejo there rise in a straight line, which coincides indeed with the main line itself, Las Pilas, Orota, Santa Clara, and several other cones without names.

The volcanos of Axusco and Telica stand a little nearer the sea and appear to form part of a second zone, which runs parallel to the main line, and consequently to the north-west[3].

The last-named volcano, Telica, is, according to Seebach, a transverse ridge with five craters, the most westerly of which still emitted a small amount of vapour at the time of his visit in the year 1864[4].

On April 11 and 12, 1849, subterranean rumbling was heard in the town of Leon. On the morning of April 13 an opening was formed at the foot of the long extinct volcano Pilas. Fragments of lava were ejected and fell to earth like freshly molten iron. This irregular eruption was followed by an abundant flow of lava during the remainder of the day, and at this time there was hardly any trembling of the ground. On April 14 the lava ceased to flow and a long series of explosive eruptions began, with ejection of stones. Squier, from whom I borrow

[1] K. v. Seebach's Besteigung des Vulcans Turrialba in Costa Rica; Petermann's geogr. Mittheil., 1865, XI, p. 322, Taf. ix. The foreland from the foot of the Turrialba to the Gulf of Nicoya is described by Attwood as consisting solely of consolidated ashes with dykes of augite-andesite; it contains the gold and silver bearing lodes of the Aguacate mountains. Attwood, On the geology of part of Costa Rica; Quart. Journ. Geol. Soc., 1882, XXXVIII, pp. 328–339.

[2] K. v. Seebach, Petermann's geogr. Mittheil., 1866, XII, p. 274.

[3] A. Dollfuss et E. de Mont-Serrat, Voy. géol. dans les Républ. de Guatemala et de Salvador (Miss. scientif. au Mexique et dans l'Amér. centr., Géologie), 4to, Paris, 1868, p. 327.

[4] K. v. Seebach, Petermann's geogr. Mittheil., 1866, XII, p. 273.

this information, visited the spot on April 22 and found the new cone 150 to 200 feet high[1].

Since then, in November, 1867, a new volcano has been formed near this place. Dickerson's account of the event is so instructive that I will extract some details from it[2].

On November 14, 1867, towards one o'clock in the morning, the eruption began with a series of explosions, which were distinctly perceived in the town of Leon, situated about eight leagues to the west of this place. A fissure opened up in the earth's crust, about half a mile in length, which diverged from the main volcanic line at a point nearly equidistant from the two volcanos Pilas and Orota, and proceeded to the south-west. Some time before sunrise on November 14, fire was seen issuing from this fissure in several places. Explosions followed one another at short intervals of about half an hour each, but the muffled sound of subterranean rumbling was almost uninterrupted. After some days two craters opened on the new cleft, which ran to the south-west, at a distance of about 1,000 feet from each other; the one to the south-west ejected volcanic material in a vertical direction, the other to the north-east hurled it forth obliquely at an angle of 45°. On November 22 these craters were visited by Dickerson: at that time the main crater had already attained a height of about 200 feet, and the aperture was about 60 feet in diameter. On the afternoon of November 27 the volcano, after a series of most violent explosions, began to eject great quantities of black sand and masses of rocks. On the next morning the country was covered far and wide with a layer of this fine black sand, which was poured down like rain from a broad shining cloud. The rain of sand continued until the morning of November 30, then the volcano became inactive, apparently exhausted by its eruptions. The sand covered the whole country within a radius of more than 80 kilometers. At Leon the layer was a quarter of an inch thick. It grew thicker towards the volcano, and the grains of sand became coarser. At the distance of a mile from the crater the grains measured from three-eighths to one-half of an inch in diameter, and the deposit was a foot deep. At the foot of the cone there was nothing but a pile of blocks from four to five feet in diameter.

At the close of the eruption, the cone itself measured 200 feet in height, the diameter of the crater was 200 feet, and its depth also 200 feet. A long band of scoria extended to the north-east. The eruption had lasted

[1] E. G. Squier, The Volcanos of Central America and the Geographical and Topographical Features of Nicaragua, Tenth Ann. Meeting of the Am. Assoc. at New Haven, Aug. 22, 1850. From the New York Daily Tribune, 8vo, 1850, pp. 5, 6.

[2] A. B. Dickerson, On the Volcanic Eruption near the city of Leon, Amer. Journ. Sc. Arts, 1868, 2 ser., xlv, pp. 131–133; reproduced in full in Al. Perrey, Note sur les tremblements de terre en 1866 et 1867 (from the Bull. Acad. roy. Belg., 1868), pp. 197–200, and in Dolfuss et Mont-Serrat, pp. 327–330.

sixteen days. The sand consisted of fragments of scoria, chrysolite, and felspar.

Thus this new cone also stands on a transverse fracture; and again, its chief centre of activity, the crater from which the ejections took place in a vertical direction, lay to the south-west. The complete cone bears some resemblance to Monte Nuovo near Puzzuoli, since it only represents a ring of ejected material and the bottom of the crater does not appear to lie much above the surrounding plain. Judging by the volume of the masses ejected, the space evacuated by them must have been extremely great, but so small a fraction of these great masses of material accumulated about the orifice that the resulting cone was only 200 feet in height.

Let us return, however, to the study of the main volcanic line.

Beyond Viejo, but nearer to the sea, and not within the course of the main line, lies the most famous volcano of this region, Mount Conseguina. Its eruption of January 20, 1835, is considered, and perhaps with justice, to have been the grandest and most terrible phenomenon of its kind for several centuries past. Dollfuss and Mont-Serrat, of whose detailed description of the mountains of Guatemala and Salvador I have frequently made use below, estimate that, according to the official reports, the area of the sea strewn with ash and pumice must have extended for 2,000 kilometers from east to west, so vast were the masses ejected from the interior of the earth. In the whole neighbourhood, even in the town of San Miguel, which is 80–90 kilometers distant from Conseguina, the most complete darkness reigned for two days and a half; the branches of the trees broke beneath the rain of sand and ash, and the birds fell dead to the ground. Even in the town of Guatemala, nearly 350 kilometers from the centre of eruption, the sun was obscured by a dark mist, and the fall of ash continued here until January 31. The earthquakes were so violent that they were propagated with terrible force towards the north-west through Guatemala to Chiapas, towards the north-east to Jamaica, and towards the south-east as far as Bogota [1].

The question again arises as to the extent of the cavity which this extraordinary eruption must have caused.

Conseguina forms, as it projects towards the sea, the southern boundary of the Bay of Fonseca, behind which rises the inactive volcano of the island of Tigré. On the north shore of the bay, Mount Conchagua is situated, which after a long pause broke forth into fresh activity on February 23, 1868. With Mount Conchagua begins the second part of the volcanic line of Central America, which proceeds more to the west than the first.

The northern part of Guatemala consists, as will be shown later, of the fragments of a unilateral mountain chain, which strikes to the east-north-east almost transversely across the Central American continent, and is continued into Jamaica and Haiti. The most northerly zone of this chain

[1] Dollfuss et Mont-Serrat, op. cit. pp. 333–340.

is limestone, then follows a zone of ancient schists, which reaches the Caribbean Sea at the end of the Bay of Amatice and to the east of it. Further to the south a narrow zone of granite appears north of the town of Guatemala, and runs to the east-north-east, following for some distance the longitudinal valley of the Rio Grande. From here to the south, nearly as far as the Bay of Fonseca, and up to a great fracture which cuts obliquely across the strike of the mountains, following approximately the coast line of the Pacific, all the mountains are composed of a rock which Dollfuss and Mont-Serrat call 'Porphyre trachytique.' On the edge and on the flank of this oblique fracture, parallel to the Pacific coast, are situated the volcanos of Salvador and Guatemala.

These volcanos are characterized by all the peculiarities which distinguish those on the line from Chiriqui to Conseguina. 'It is quite clear,' write Dollfuss and Mont-Serrat, 'that we are not dealing with a series of isolated volcanos, arranged in a more or less straight or broken line, but with a *succession of small systems*, which are fairly independent of each other, and occur at distances which vary within comparatively narrow limits. Each of these groups is formed of a more or less considerable number of cones and craters, some extinct, some still active, arranged in a straight line, the direction of which is nearly perpendicular to that of the main volcanic axis.' '... It seems therefore as though at each point of eruption a fissure had been formed perpendicular to the main fissure; on this transverse fissure the volcanic funnels stand, formed one after the other by an advancing course of eruptive activity. That this course has always followed a fixed and unchanged direction we cannot assert, but we may observe in passing, and without for the moment attempting to draw any conclusion, that in many cases, where one of the volcanos of a particular group is still active, it is situated at the southern extremity of the system [1].'—

Conchagua is followed on the main line in a west-north-west direction by the active volcano San Miguel, 2,153 meters in height; between it and Conchagua a broad field of lava extends. Then follow, also on the main line, the smaller eruptive centres of Chinameca and Tecapa, then San Vicente (2,400 meters), and finally Lake Ilopango, in the midst of which, in February, 1880, a new volcano appeared. This has been very exactly described by Rockstroh [2].

The lake is surrounded by steep cliffs of ancient rocks. Inland to the north-north-east lies the small extinct volcano of Cojutepeque.

Beyond Lake Ilopango rises the volcanic group of San Salvador, and

[1] Dollfuss et Mont-Serrat, op. cit. pp. 296, 297.

[2] Edwin Rockstroh, Informe de la Comision scientif. del Instit. Nacion. de Guatemala nombr. p. el Sr. Ministro de Instrucc. Publ. para el estudio de los fenómenos volcán. en el Lago de Ilopango, 8vo, Guatemala, 1880, p. 61, and map.

then, projecting in a fairly marked manner towards the sea, the remarkable volcano of *Izalco* (Fig. 5, 21).

Karl von Seebach, whose extensive work on this subject has hitherto been published only in fragments, these, however, of the very highest value, has furnished us with a highly instructive description of this volcano [1].

It arose, like the centres of eruption we have just described near Leon, like Jorullo and Monte Nuovo, in late historic times; its eruptions commenced on March 29, 1793. It lies to the south-west of the extinct volcano Cerro Redondo, and has been continuously active, with rare intervals of repose, since its appearance; for many years its eruptions have been as regular and rhythmic as those of Stromboli. It rises, according to Seebach, 597 meters above the sea, and 292 meters above the floor of the church at Izalco. From these measurements, Seebach estimates the volume of the cone at 26·88 million cubic meters, and the ejection of material, assuming a persistent uniform activity since 1793, at 0·7 cubic kilometer per minute. As a matter of fact the rate of ejection must have been much greater, since in the case of violent eruptions only a small proportion serves to build up the cone, while the remainder is carried far away over land and sea.

A detailed comparison of the volcanos lying beyond Izalco will only be possible after the publication of K. von Seebach's investigations; meanwhile the accompanying sketch, Fig. 5, drawn from the map of Dollfuss and Mont-Serrat, may serve to show how far the development of the transverse fissures has proceeded. Furthest to the east stands the long series of the Chiquimula volcanos (14–18), then that of Cerro Redondo (12, 13). All the craters of these two groups are extinct. Then follow on the main line the active Pacaya (11) and the lofty volcano d'Agua (10), so named on account of the devastating eruption of water which took place in the year 1541, the result probably of the fracture and evacuation of a crater lake. These are succeeded by the mighty transverse line of the volcano de Fuego (7, 8, 9) with an active crater at the south-west end, then the equally gigantic group of the volcano d'Atitlan (4, 5, 6) with the active chimney again at the south-west end, the extinct volcano San Pedro (3), and finally on the Mexican frontier the two eruptive centres of Quezaltenango (1, 2). Of these, that which is in activity is, by exception, the one to the north-east or furthest away from the sea.

We thus see on the whole line, from Chiriqui in the south-west, to the Bay of Fonseca and the Mexican frontier in the north-west, a frequent

[1] K. v. Seebach, Ueber den Vulcan Izalco und den Bau der central-americanischen Vulcane im Allgemeinen; Nachr. v. d. kön. Gesellsch. d. Wiss. a. d. G. A. Univ. zu Göttingen, 1865, pp. 521–547. Prof. v. Fritsch has had the great kindness to communicate to me from Seebach's manuscripts a sketch of the neighbourhood of Izalco. Dollfuss and Mont-Serrat, strange to say, were not aware of the fact that Seebach had ascended this volcano but a short time previously.

recurrence of the following facts: The volcanos stand either on long independent transverse lines, which meet the main line at a right angle or less, or else the individual volcanos themselves show a tendency to shift their centre of eruption transversely across the main line, and—with the single exception of the Cerro Quemado in the group of Quezaltenango in the extreme north-west—*this displacement is, it would appear, in every case effected in the direction of the Pacific Ocean.*

The displacement is fairly rapid, and already within the last century several new centres of eruption have opened up in this direction, not to

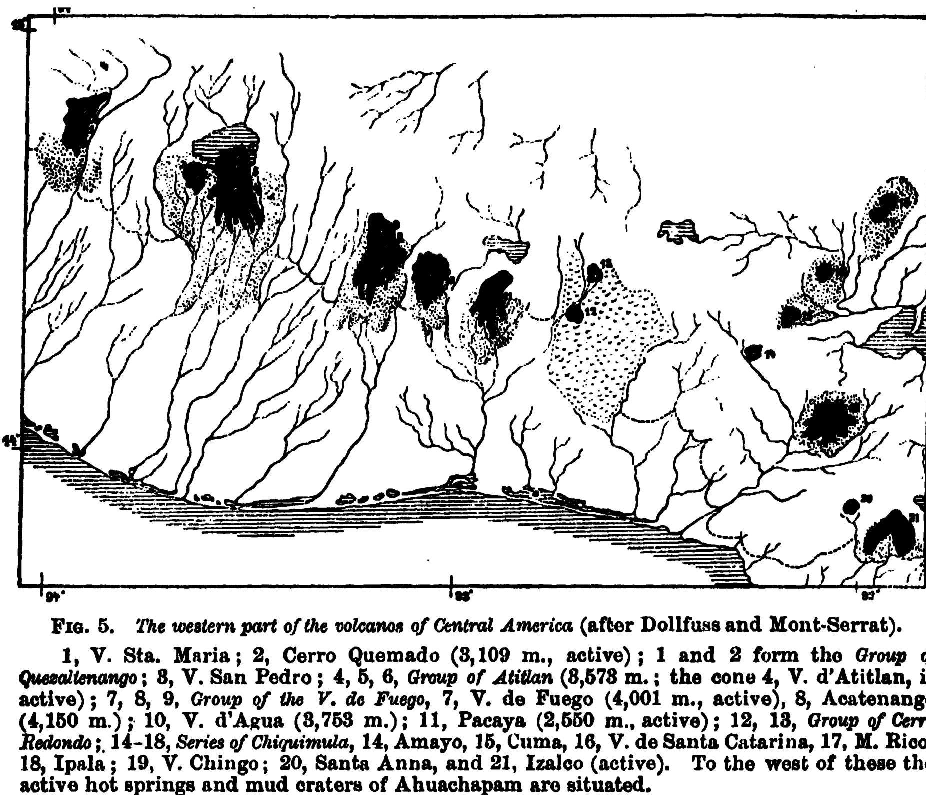


FIG. 5. *The western part of the volcanos of Central America* (after Dollfuss and Mont-Serrat).

1, V. Sta. Maria; 2, Cerro Quemado (3,109 m., active); 1 and 2 form the *Group of Quezaltenango*; 3, V. San Pedro; 4, 5, 6, *Group of Atitlan* (3,573 m.; the cone 4, V. d'Atitlan, is active); 7, 8, 9, *Group of the V. de Fuego*, 7, V. de Fuego (4,001 m., active), 8, Acatenango (4,150 m.); 10, V. d'Agua (3,753 m.); 11, Pacaya (2,550 m., active); 12, 13, *Group of Cerro Redondo*; 14–18, *Series of Chiquimula*, 14, Amayo, 15, Cuma, 16, V. de Santa Catarina, 17, M. Rico, 18, Ipala; 19, V. Chingo; 20, Santa Anna, and 21, Izalco (active). To the west of these the active hot springs and mud craters of Ahuachapam are situated.

The active volcanos are 2, 4, 7, 11, 21.

The dotted line marks the foot of the mountains. The volcanos are surrounded by their ashes and lavas, 12 and 13 by a great field of basalt.

speak of the numerous concussions of the ground and the eruptions from already existing chimneys, which reveal, we might almost say, an uninterrupted movement of the earth's crust in these regions.

With regard to one of the more violent of recent earthquakes, that of December 19, 1862, and the weeks following, P. Lizarzaburu made the remarkable observation that it did not proceed from a single point, but from a considerable length of the main line, and in particular from the

volcanos d'Atitlan, de Fuego, and Izalco. The greatest devastation was caused in the neighbourhood of these three volcanos. At the magnetic observatory in Guatemala the first and most violent concussion began on December 19, 1862, *7 h. 25′* p.m., with a shock from the south-west, and this was followed immediately by a movement from the south-south-west, that is, from the neighbourhood of Izalco. On December 20 further shocks occurred, coming from the same direction. After an interval, which lasted until December 26, the shocks were renewed from the south-west, and these continued into the second half of the month of January[1].

The concordance of these results with the observations which have been made on the displacement of the seismic centres along the main line of Calabria, show us above all that in both districts great and interdependent movements of the earth's crust take place as it were beneath our very eyes, and prepare the way for yet greater ones. But while in Calabria the clearest signs of these processes are to be found on the peripheral fracture itself, in Central America the tendency is to form further transverse clefts in the direction of the Pacific Ocean, as is seen in numerous examples throughout the whole of the long zone which extends from the Chiriqui to the Mexican frontier, first obliquely across the continent and then along the Pacific coast, from lat. 8° 48′ to about 15° N. These transverse fractures may be regarded possibly as radial cracks, dependent either on one very large and continuous area of subsidence, or on two such areas, which meet in the neighbourhood of the Bay of Fonseca. The process would then consist in the opening up of radial cracks *from without inwards.* The longest of the radial lines, that of Chiquimula, extends far beyond the peripheral zone, which is otherwise very distinctly marked.

A very large part of the Pacific side of Central America is thus actually in process of sinking. The subsidence takes place in a direction transverse to the strike of the mountain chain, formed of granite and stratified rocks, which extends towards Jamaica and Haiti; it does not appear to stand in any relationship to the structure of the chain.

### D. *The statements concerning spasmodic elevation of the west coast of South America.*

During violent earthquakes in Calabria, stones lying on the road were projected into the air. During the earthquake of Chili, on November 7, 1837, a mast which was sunk with its lower end 10 meters deep in the ground and made fast with iron cramps is said to have been jerked out without any injury to the aperture in which it stood[2]. Alexander von

[1] J. A. Lizarzaburu, Observaciones meteorol. correspond. al año de 1862, hechas en el observat. del Seminario de Guatemala (from the Gaceta de Guatemala), 8vo, 17 pp. I owe the communication of these observations to Herrn E. Rockstroh in Guatemala.

[2] Lettre de M. Gay à M. Arago; Comptes rend. 1838, VI, p. 833.

Humboldt relates even that, during the destruction of Riobamba, in the year 1797, a vertical shock 'like the explosion of a mine' hurled the bodies of many of the inhabitants on to the hill la Cullca, which is several hundred feet high and lies on the other side of the rivulet of Lican [1].

These phenomena have indeed very little resemblance to those movements of the earth by which mountains are produced, and still less with those supposed movements of the mass of the planet, which are said to be extensive, uniform, and slow, and which are designated by the name of *continental, secular oscillations.* They point rather to a sudden local upward jerk, perhaps a rebound due to unloading. That a permanent though trifling change of position may take place in an upward direction is *a priori* not at all improbable, but it is the more remarkable that although such a change has been often alleged it has, so far, nowhere been proved with any degree of certainty.

The best known example, that which is most frequently cited in text-books and is supposed to be the best established, is the alleged repeated elevation of the west coast of South America during great earthquakes. I will attempt to examine this case according to the existing reports.

I must preface my remarks by stating that the attendant circumstances of this case are particularly calculated to produce an impression favourable to the hypothesis of repeated spasmodic elevations.

In the first place one of the greatest lines of volcanos in the world runs parallel to this coast, which extends in an almost straight line through many degrees of latitude, and this fact alone could not fail to influence opinion at a time when theories were maintained as to the connexion between volcanic force and elevation which differed from those of the present day.

In the next place this coast is bordered for long distances by a fringe of talus, deposited in terraces, in which sea-shells are found above the existing level of the sea. These terraces certainly show that considerable changes have taken place in the position of the strand, but they do not indicate any connexion with the earthquakes of the present day; they belong to a remote period, and will be discussed later as part of a phenomenon, which is manifested far beyond the area shaken by these earthquakes.

Finally 'kitchen middens' occur at many localities along the margin of the coast, and at several places are still in process of accumulation.

When Darwin visited these coasts in 1835 little was known as to the wide distribution of such remains. It must therefore have filled him with the greatest astonishment to meet with a thread, pieces of wicker-work, and other traces of human activity in a deposit of sea-shells on the island of San Lorenzo, near Callao, at a height of 85 feet above the sea, and he may well, according to the state of knowledge at that time, have

[1] Humboldt, Kosmos, I, p. 210.

regarded it as a proof of recent elevation[1]. Dana, who visited the place some years later, has already explained the circumstance[2].

Before proceeding to examine the accounts from South America, let us call to mind the fact that the seismic waves of the ocean, while they roll over the mainland destroying and rending up all before them, also raise and carry away extraordinary quantities of loose sediment from the sea bottom. After the great inundation of Callao on October 28, 1746, large heaps of sea-sand and pebbles were left on the ruins of the devastated city[3]. In this way, when an island divides the seismic waves, or when any two currents of seismic origin meet, new land may easily be formed. The East Indies afford a striking example of this process. On the coast of Malabar, north of Cochin, the island of Vaypi was upheaved during a great earthquake in the year 1341. It consists of sea-sand and of the same sediments as at the present day are carried down from the Ghâts to the plains of Malabar. At the same time the country around the mouth of the river Cochin was completely transformed, and so powerful an impression did this phenomenon make on the Hindoos, that they dated from it a new era, 'Puduvepa[4].'

Let us now return to South America, and first of all devote our attention to the observations collected by Tschudi regarding the supposed repeated elevation and depression of the country round *Callao*.

We have already mentioned the 'kitchen middens' of Callao. Independently of these it is asserted that the island San Lorenzo, which is now two nautical miles distant from the continent, has sometimes been nearer to the land, sometimes more remote. In the year 1742 the distance was about the same as at present; during the great earthquake of 1746 a subsidence of the town is said to have taken place; by a supposed elevation of the coast in 1760 the island was again brought so near the land that boys could throw stones across to it. Between the island and the mainland lay a shallow called 'Camotal,' because previously when it was dry, 'camote,' that is potatos, had been grown on it[5].

The place in question is a tongue of land lying between San Lorenzo and the mainland; at one time it is in existence and grows larger either by slow silting-up or by a sudden deposition of sediment, at another it is torn up and destroyed, perhaps by the breaking over it of a seismic wave. We cannot deduce from this an oscillation of the mainland. Nor do the accounts

[1] C. Darwin, Journal of Researches, 8vo, 1839, p. 451, *et passim*.

[2] C. Wilkes, U. S. Exploring Expedition, X, Geology, by J. D. Dana, 4to, 1849, p. 591.

[3] A True and Particular Relation of the dreadful Earthquake which happened at Lima, &c., p. 146. In this detailed account no mention is made of an elevation of the land.

[4] Newbold, Summary of the Geology of South India; Journ. Roy. Asiat. Soc., 1846, VIII, in particular p. 280 et seq., quotes Thomson, Madras Journ. Litt. Science, Jan. 1837, pp. 176, 177.

[5] Von Tschudi, Peru, Reiseskizzen, 8vo, 1846, I, pp. 43-49.

of 1746 speak of the subsidence of the town; on the contrary, they describe clearly the rising of the sea-wave and its final plunge over the land.

The accounts which have become most widely known relate to the earthquakes in certain parts of South America in the years 1822, 1835, and 1837.

The earthquake of November 19, 1822, seems to have had its origin to the north-east of Valparaiso. The most authoritative account of the asserted simultaneous elevation of the land is a letter from Mrs. Maria Graham, which was published by the Geological Society of London. According to this letter the whole coast appeared on the following morning to have been raised above its former level over a distance of more than one hundred miles. In Valparaiso the elevation amounted to three feet or so, in Quintero to about four feet. At high tide part of the bed of the sea was seen to be dry, with oysters and other shell-fish clinging to the rocks on which they had grown, now however dead and diffusing evil odours[1].

I pass by the later observations of Drs. Meyen and Anderen, as they were not made until some years after the event, and hardly add anything new.

But the definite statements of Mrs. Graham are opposed by other statements equally exact, the most important of which however were not published until 1835; these are contained in the letters of Captain Belcher, Lieutenant Bower, and the well-known malacologist Cuming, and are also addressed to the Geological Society[2].

Captain Belcher doubts whether any alteration in level took place which could have influenced the soundings, because no statement to this effect was sent in to the ships of the British Navy stationed on the coast of Chili, as it certainly would have been if the matter had appeared of any importance to the English residing in those parts. Lieutenant Bower was in Valparaiso in February, 1823, and found everything in the

[1] Mrs. Maria Graham, An Account of some Effects of the late Earthquakes in Chili, extract from a letter to H. Warburton, Esq.; Trans. Geol. Soc., 1822, 2nd ser., I, pp. 413–415. Greenough, as president of this distinguished society, had in his annual address on June 4, 1834, expressed serious doubts on the subject of these statements; Mrs. Calcott (formerly Mrs. Graham) replied in a separate communication, which however adduced no new facts. Letter to the President and Members of the Geol. Soc., &c., 8vo, London, 1834.

[2] Proc. Geol. Soc., 1838, II, p. 213; Captain Belcher's and Mr. Cuming's letters were communicated at the meeting of Dec. 2, 1835. At a later date E. Chevalier (in the Voyage of the *Bonite* and in a Note sur la constit. géol. des envir. de Valparaiso et sur le soulèvement du sol de la côte du Chili, Bull. soc. géol. de Fr., 1843, XIV, pp. 396–401), after a comparison of the soundings made by Ulloa, 1744, and by Dupetit-Thours, 1837, also denied that any important alteration had occurred in the neighbourhood of Valparaiso, but attempted to show that all the shell-bearing terraces along the coast had been produced by waves of seismic origin.

same condition as in the previous year, but since the earthquake the water had gradually retired from the landing-place and the market-place, and a number of buildings had been erected where previously the sea had flowed.

Mr. *Cuming* was in Valparaiso from January, 1822, to 1827, and with a few interruptions until 1831. He witnessed the earthquake, and his house was destroyed. He heard that the sea had retired, and had returned with great force. On going down to the shore the next morning he observed the effect of the wave, but with regard to the sea he perceived nothing, except that the tide was high. Nor did he hear anything of the elevation of the coast or of isolated rocks; neither he nor his friends could agree with Mrs. Graham's statements. He had, both before and after the earthquake, and up to the close of his stay, collected seaweeds, limpets, barnacles, and the like on the reefs of the bay, but had on no occasion perceived any change of level. The idea that the land had risen may have been caused by the fact that, since the earthquake, an accumulation of detritus had been formed at a place which had previously been reached by the tide, and on which houses and even little streets had now been built. The greater part of this alluvial land only dates, however, from June, 1827, that is, five years after the earthquake, and was produced by heavy rain which carried down the loose granite soil of the neighbouring hills.

After the preceding remarks I consider the discussion of the first case, that of the earthquake of 1822, as closed.

The next is that of *the earthquake of Concepcion on February* 20, 1835.

Let us first glance at the scene of the most important events. Its geological structure has lately been described by Enrique Concha i Toro. The coast here, between 36° 30′ and 37° 30′ S., consists of the ancient rocks of the littoral Cordillera of Chili, on which lie patches of Cretaceous, Tertiary, and Quaternary deposits[1].

To the north of the town of Concepcion lies the Bahia de Talcahuano, also called the Bay of Concepcion, on the south-east shore of which Penco, the ancient capital, is situated; towards the north-east lies the green sandstone of Tomè, rich in Baculites. The island of Quiriquina extends transversely across a great part of the bay.

To the south-east of Concepcion lies the much more extensive Bahia de Arauco, bounded on the west by Punta Lavapiès, and its prolongation the island of Santa Maria. The sea-coast as far as Point Lavapiès is formed of Cretaceous beds, and these are continued into the middle of the island of Santa Maria; to the west of this Cretaceous

[1] Don Enrique Concha i Toro, Estudio sobre el carbon fósil que se explota en Chile, Anal. Univ. Chile, 1876, pp. 337-423 and two plates; also Sievcking, Petermann's geogr. Mittheil., 1883, XXIX, pp. 57-61.

band the island is composed of Tertiary beds, to the east of Quaternary, or even still younger deposits. East of Point Lavapiès the Rio Tubul enters into the sea.

Captain Fitzroy, in whose company, as is well known, Charles Darwin

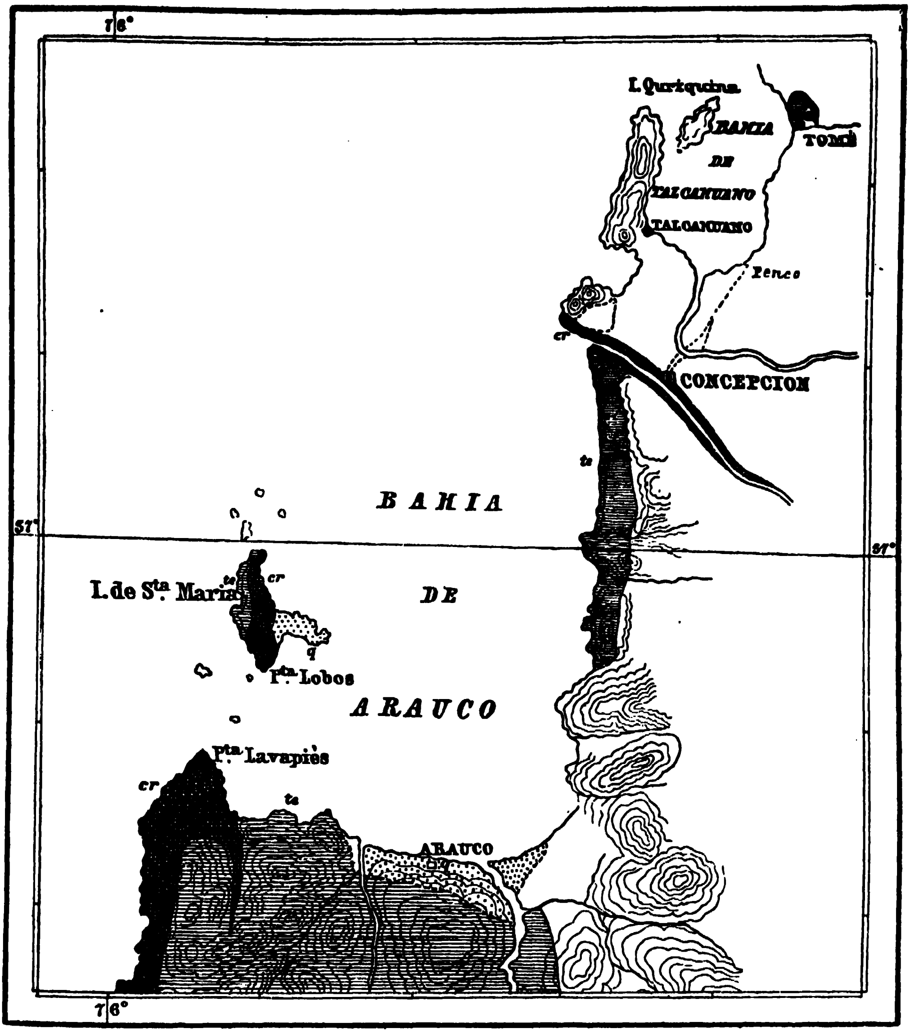



FIG. 6. *Scene of the earthquake of February* 20, 1835 (after Concha i Toro).
*cr* = Cretaceous system ; *te* = Tertiary ; *q* = more recent deposits.
The parts without hatching are occupied by the older rocks of the coast Cordillera.

made his voyage in the *Beagle*, happened to be in Concepcion on the momentous day, and has furnished a graphic account of the occurrence [1].

[1] R. Fitzroy, Sketch of the Surveying Voyages of H.M. Ships *Adventure* and *Beagle*; Journ. Roy. Geogr. Soc., 1836, VI, pp. 319-331. Still further to the south the island of

He begins by mentioning that on February 20, 1835, at ten o'clock in the morning, the population were surprised to see large flocks of sea-birds flying inland, a quite unusual occurrence. At twenty minutes to twelve the first shock took place at Concepcion, and was immediately followed by general devastation. The earthquake appeared to come from the south-west. The low-lying and loose ground suffered most, and seemed to detach itself from the more solid mountains. At Talcahuano and Penco the same phenomena occurred.

Half an hour after the principal shock the sea had retired so far that vessels which anchored in seven fathoms of water lay dry. All the reefs, shallows, and sandbanks in the Bay of Talcahuano were exposed to view. Then a monstrous wave forced its way through the western channel between Quiriquina and the mainland, and rising to a level thirty feet above high tide swept all before it. This was followed by a second yet greater and more tempestuous wave, and finally, after some minutes, by the third and most powerful. Then the sea appeared to be exhausted. Earth and water trembled. For three days the sea continued to ebb and flow irregularly and frequently. Some hours after the occurrence it rose and fell two or three times an hour.

East of Quiriquina a less violent wave rolled in. At the same time, at several places beyond Quiriquina and in the Bay of San Vincent, smoke-like eruptions appeared to take place in the sea. These were followed by a whirlpool, as though the sea were about to pour into a cavity.

*For some days after the ruin,* Fitzroy continues, *the sea did not rise to the usual marks by four or five feet vertically. Some thought the land had been elevated, but the common and prevailing idea was that the sea had retired. This difference gradually diminished, till in the middle of April there was a difference of only two feet between the existing and former high-water marks.*

*The proof that the land had been raised exists in the fact that the island of Santa Maria was upheaved nine feet.*

The elevation of the south end of this island amounted to eight feet, of the middle to nine feet, and of the north end to ten feet. The island was twice visited, at the end of March and at the beginning of April. On the first occasion the elevation of eight feet was observed; later on, doubt having arisen, the visit was repeated, and the first observation was confirmed in various ways. Near Tubul, on the mainland, the elevation amounted to six feet.

So far the most important statements of Fitzroy: Darwin was at this time in Valdivia.

Mocha (38° 12′) is said to have been raised two feet, but the accounts are wanting in precision.

We see from this that on a line starting from Tubul on the mainland, and proceeding northwards along the island of Santa Maria, changes of level were produced, which amounted to six feet in Tubul and increased to eight, nine, or ten feet on Santa Maria; while near Talcahuana the difference was at first four to five feet and had decreased by the middle of April to two feet. In a later account Darwin says:—

*It appears from the investigations of Captain Fitzroy that both the island of Santa Maria and the city of Concepcion sunk in the course of a few weeks, and lost a part of their original elevation* [1].

Caldcleugh, who was also an eye-witness of these events, writes:—

*Both Captain Fitzroy, and Captain Simpson of the Chilian Navy, were of opinion that the uprising of the strata, both in this island and in Concepcion, was considerably greater, and that many subsequent minor oscillations may have caused a subsidence to the level before recorded* (8–10 *feet*) [2].

On May 3, 1835, not long after Fitzroy, Captain Coste anchored near Santa Maria; he too found nine feet less anchoring ground than in the previous year. He saw on the shore the same traces of change as Fitzroy had observed, but unfortunately made no exact measurements [3].

Simultaneously with the reports of the observers of the *Beagle* an account by Don Mariano Rivero and a letter from Colonel Walpole were laid before the Geological Society; both pronounced against any change of level in Chili during this earthquake [4].

Even Charles Lyell, himself the keenest champion of the view that the mainland had risen, found occasion to remark later that the trifling elevation of the old buildings of Penco above the sea might easily lead to the supposition of a permanent elevation of the coast, and might throw light on the opinion, expressed of late years, that after every elevation the coast of

[1] C. Darwin, Geological Observations on the volcanic Islands, &c., 2nd ed., 1876, p. 237; likewise Domeyko, 'Sin embargo, por las noticias recibidas posteriormente por Fitzroy, parece que desde entónces el mencionado puerto de la isla ha ganado multo en profundidad, i que toda esta parte de la costa de Chile, que el terremoto de 1835 habia levantado, ha vuelto a bajar i hundirse en el mar'; Solevantamiento de la Costa de Chile, Anal. Univ. Chile, 1860, p. 576.

[2] A. Caldcleugh, An Account of the great Earthquake experienced in Chile, Feb. 20, 1835; Phil. Trans., 1836, p. 24.

[3] Captain Coste, Comptes rend., 1838, VII, p. 706.

[4] In the meeting of January 4, 1837. We find in the Proc. Geol. Soc., II, p. 179, a note by Lieut. Freyer on apparent elevation of land with reference to the shell-beds of Arica and the island of St. Lorenzo near Callao; p. 209, Fitzroy's first report on Santa Maria and a communication by R. E. Alison on this subject; p. 444, a letter by Caldcleugh, and p. 446, another by Darwin; then the essay by Rivero in the newspaper 'El Araucano,' and finally Col. Walpole's letter to Palmerston. The last two observers, as we have said, dispute any elevation or subsidence of the ground.

Chili showed a tendency to gradually subside, and to return to its previous level [1].

Under these circumstances all the conclusions which the defenders of the elevation theory have drawn from this occurrence are worthless, and the question presents itself whether, for this temporary and inconsiderable difference in level, a much simpler explanation may not be found in the excessively violent disturbance of the sea. An important current flows at present between Point Lavapiès and Santa Maria into the Gulf of Arauco, which it leaves in a northerly direction; and the question arises whether this might not have been diverted for a time, and, if so, whether a temporary emergence of the land might not have followed as a natural consequence.

The statements concerning a further elevation of land during the earthquake of *Valdivia* on November 7, 1837, are confined to a communication from Captain Coste regarding the island of Lemus in the Archipelago of Chonos. On his visit to the island on December 11 of the same year, he found that the sea bottom had risen more than eight feet, rocks which were formerly constantly covered by the sea were now laid bare, a great quantity of decomposing material, sea-shells, and fishes covered the strand, which was surrounded by a great number of uprooted trees washed thither by the sea. Captain Coste saw in this traces of a sudden elevation of the land or of the oscillation of the sea [2].

This last alternative seems to me to be the decisive question; it must first of all be definitely stated whether it was really rocks or whether it was sand-banks which were laid bare, and also to what extent the sea which had transported the trees might not have diminished its depth by means of the accumulation of sediment. The movement of the ocean during the earthquake was so violent that floods were caused by the waves on the Gambier Islands, and on some of the islands of Tonga and Samoa. On Wawau [Vavao] in the Tonga group the unusual agitation of the sea was observed for thirty-six hours [3].

But at several points on the west coast of South America somewhat ancient buildings exist which by their position contradict the hypothesis of any considerable elevation of the ground. Bibra, on finding at Algodon Bay burial-mounds and traces of old buildings forty to fifty feet above the sea-level, was led to this conclusion [4]; so was David Forbes, when he saw on the coast of Bolivia a large number of Indian tumuli scarcely twenty feet

[1] Lyell, Principles of Geology, XI, ed. 1872, II, p. 156.

[2] Comptes rend., 1838, VII, p. 707.

[3] Dumoulin, Lettre à M. Arago; Coïncidence de date de quelques mouvements extraordinaires de la mer, observés dans l'Océanie, avec le tremblement de terre qui en 1837 renversa la ville de Valdivia au Chili; Comptes rend., 1840, X, pp. 835–837.

[4] V. Bibra, Die Algodon-Bai; Denkschr. k. Akad. Wiss. Wien, 1852, IV, pp. 75–116.

above the sea[1]. As to Valparaiso itself, Darwin has shown that the buildings on the island prove that the greatest possible elevation could not have exceeded fifteen feet for the last 200 years[2].

The most competent authority on this question, Professor R. Philippi, of Santiago, in his description of the so-called desert of Atacama, some years ago, laid particular emphasis on the fact that he had found no evidence which would point to an elevation of this district in recent or even in historical times, and he has since then expressly stated that after the mighty earthquake of Arica on August 18, 1868, no reports concerning elevation or subsidence of the ground were received either from the Peruvian or Chilian coast[3]. At my request he had the kindness to again institute inquiries, and wrote me on June 12, 1882, 'My investigations on this subject have unfortunately produced no result. There are at present but few persons in Chili who are interested in scientific questions, and in 1835 there were yet fewer; the captains of harbours and the sailors of that time are long since dead. I can only repeat that no recent elevations of the coast of Chili are known to me, but I have often heard it stated in Talcahuano and Corral that the earthquake of 1835 had caused changes in the sea-bottom, and that in certain shallow places, which are well known to fishermen, the depth of the water had diminished. The assertions of the fishermen are in my opinion not sufficient evidence; these people do not pay much attention to precise dates, and in the Bay of Corral, for example, it is quite possible that the deposits of the river Valdivia may have gradually diminished the depth of the sea, and that when this had become very noticeable, it was ascribed to the earthquake in question. There are a large number even of educated people who never adopt the most simple and natural method of explanation.

'It is also generally reported that the earthquake of 1835 caused an alteration of depth in the harbour of Ancud; I have heard nothing of an elevation of the whole coast. That is, it is true, no proof to the contrary, for a trifling elevation of a few feet might easily have escaped the notice of the inhabitants . . .'

After a detailed account of kitchen débris and relict strand-lines, which will be quoted later, Professor Philippi adds: 'I must frankly confess that my observation and experience do not incline me to believe that the Andes and other high mountains have arisen simply as the result of many thousands of such earthquakes, any single one of which would have raised the ground a few inches or a few feet at the very most.'

[1] D. Forbes, On the Geology of Bolivia and S. Peru; Quart. Journ. Geol. Soc., 1861, XVII, p. 10.

[2] C. Darwin, Journ. Res., p. 452; Proc. Geol. Soc., II, p. 488. The Church of St. Augustin in Valparaiso furnishes an argument against elevation.

[3] Philippi, Die sogenannte Wüste Atacama, Petermann's geogr. Mittheil., 1856, p. 56, and in letter form in Hochstetter, Erdbeben von Peru und seine Fluthwellen.

This leads us to the important conclusions which were drawn some years ago from the observations in Chili.

The earthquake of February 20, 1835, gave rise to one of the most important works on the elevation of mountains, indeed I may say to the only attempt, based on direct observation of nature, to establish more exactly the older theories concerning the force which is supposed to have raised up mountain chains. The author of this work is Charles Darwin [1]. Since that time no second attempt, or at least no attempt of equal importance, has been made in this direction. To-day, more than half a century later, it is possible to hold other opinions on these questions and yet to recognize the boldness of the generalizations, which even then revealed the master.

Darwin saw the awakening activity of the volcanos during and after the earthquake; he believed he saw elevation, although not uniform elevation of the solid ground; in addition he saw the terraces along the coast. But he also knew that similar terraces occur on the east coast of South America, where there are no volcanos and no earthquakes. The earthquakes must therefore have appeared to his eyes as the local expression of a universal force. The secular contraction of the earth, a theory already eagerly advocated by several investigators, Darwin justly held to be entirely unsuited to explain those intermittent elevations which the terraces betrayed, and thus he reached the conclusion:—

*That the form of the fluid surface of the nucleus of the earth is subject to some change, the cause of which is entirely unknown and the effect of which is slow, intermittent, but irresistible.*

Let us now glance at a map of South America, and let us imagine the great continent divided into four unequal parts by lines following its greatest length from north to south and its greatest breadth from east to west. Let us also anticipate a later chapter by stating here the fact that the terraces attain their greatest development towards the south and decrease both on the east and west coasts towards the north until they finally disappear.

We see that the south-western part of South America, which includes Chili and specially concerns us here, presents volcanos, earthquakes, and terraces; the south-eastern part shows terraces, but no volcanos and seldom earthquakes; the north-western has volcanos and earthquakes, but no terraces; the north-eastern has earthquakes, but no volcanos and no terraces.

A closer examination shows, as already pointed out, that the terraces diminish as we approach the equator and are altogether absent in the north, while the earthquakes on the other hand follow the course of the great mountain chains. As these swerve round into the north-east, so does the seismic zone, and earthquakes occur in the north-eastern part of South

[1] C. Darwin, On the Connexion of certain Volcanic Phenomena in South America and the formation of Mountain Chains and Volcanos as the Effect of the same Power by which Continents are elevated; Trans. Geol. Soc., V, 1838, pp. 601–631, pl. xlix.

America. The terrible earthquakes of Carácas occurred far outside the region of volcanos and terraces.

The collocation of these phenomena in Chili is then an argument of no great weight as regards their causal connexion, and in the north of South America other opinions as to the nature of earthquakes have arisen. In the same year, 1835, Boussingault declared that the greatest earthquakes of the New World have no connexion whatever with eruptions. Their origin must be ascribed to an actual subsidence (*un véritable tassement*) in the interior of the Cordilleras. 'This subsidence of the Cordilleras, which must have been so frequent, immediately after their elevation, still continues in our time. I do not hesitate to ascribe to this cause most of the great movements which so often convulse the mountains [1].'

*K. Fuchs* remarks that 'among thousands of earthquakes, *not a single case of subsidence has occurred*, since the time when earthquakes have really been scientifically observed and their accompanying phenomena, as well as their effects, examined [2].' It is certainly remarkable that in spite of the continually increasing attention which is paid to this subject, for many years past no fresh evidence as to the elevation of the land in South America has been forthcoming, and the supposition of Fonck, that the reason for this may lie in the greater distance of the centres of shock from the coast, does not seem to me to be sufficiently supported by the existing evidence [3].

The following summary gives in my opinion a correct account of the often alleged spasmodic elevation of the west of South America:—

1. In *Callao* the presence of kitchen débris gave rise to erroneous theories; here we are really dealing with the repeated deposition and destruction of a bank on the *landward* side of the island of San Lorenzo.

2. In the case of *Valparaiso*, 1822, the most competent eye-witnesses, such as Cuming, have emphatically denied that the coast-line experienced any alteration.

3. During the earthquake of *Concepcion*, 1835, the movement of the water of the Pacific Ocean was so violent, that soon after the shock some few feet of land on the coast were laid dry, but not permanently; it was however several weeks before the equilibrium of the sea was again restored.

4. With regard to *Valdivia*, 1837, no definite evidence whatever exists.

5. In none of the numerous earthquakes which have since occurred in the west of South America has an elevation of the land been observed.

[1] Boussingault, Sur les tremblements de terre des Andes; Ann. chim. phys., 1835, t. 58, pp. 81, 85. The examples quoted refer, it is true, only to the collapse of mountain summits; but the views expressed on the elevation of mountains in a solid state and the composition of the chains from segments of various size are very remarkable for that time; cf. also Humboldt, Kosmos, IV, pp. 219, 490.

[2] K. Fuchs, Vulcane und Erdbeben, 8vo, 1875, p. 178; likewise the anonymous work, Scepticism in Geology and the Reasons for it, 8vo, London, 1877, p. 10 et seq.

[3] F. Fonck, Las agitaciones oceánicas causad. en las costas del Pacifico por el terrem. d. 13. agosto 1868; Anal. Univ. Chile, 1871, pp. 302, 303.

## *CHAPTER III*

# DISLOCATIONS

Resolution of stresses. Dislocation by *tangential* movement. Folding. Imbricated structure. Overthrusts or *Wechsel*. Dislocation on flaw (*Blatt*) planes. Torsion. Dislocation by *radial* movement. Subsidence on a yielding base. Flexures and faults. Networks of fracture. Caldron subsidences. Dislocation by *combined radial and tangential* movement. Backfolding and squeezing in. Forefolding.

A complete revolution of opinion has of late years taken place as regards the formation of mountain chains. Apart from the excellent but older work of Favre, important material has been contributed by many investigators to a more correct conception of their structure, based on wider knowledge of the facts; we might mention in Europe alone Heim, Baltzer, Mojsisovics, and other investigators in the Alps, Paul in the Carpathians, Credner in the Erzgebirge, Lossen in the Harz, M'Pherson in Spain, and many others. It would thus be superfluous to attempt a refutation of the older views on this subject. On the other hand, we must confess that the more recent theories as to the formation of mountain ranges by means of universal movements, in relation to which all rocks are equally passive, are as yet only established in their most elementary principles. To determine the details of the process by exact investigation and comparison of particular cases is the task of the next few years. This goal endows with heightened interest every careful investigation into the nature of a well-marked dislocation, every conscientious representation of a great artificial section, such as the section of the Gotthard by Stapff, or that of the Bötzberg by Moesch, nor is it without gratitude that we turn anew to the treasure-house of older observations. I should thus like to acknowledge here the manifold inspiration I have derived from von Carnall's treatise on the fissures in the Carboniferous group, a work now more than half a century old. Nor do I hesitate to confess that, in spite of the interest attaching to the numerous attempts to produce the phenomena of faulting and folding by artificial means, yet the investigation of decisive points in Nature herself seems to me to be for the moment of much greater importance. The transverse section of a single fragment of folded schist, or the exact representation of a section laid bare in a mine, as for example Köhler's sketches in the Carboniferous basin of Westphalia, lead us to a direct understanding of a number of mechanical processes which have hitherto seldom met with the attention they deserve[1].

[1] G. Köhler, Ueber die Störungen im westphälischen Steinkohlengebirge und deren Entstehung, Zeitschr. f. Berg-, Hütten- u. Salinenwesen, 1880, XXVIII, pp. 195–210,

*The dislocations visible in the rocky crust of the earth are the result of movements which are produced by a decrease in the volume of our planet.* The tensions resulting from this process show a tendency to resolve themselves into *tangential* and *radial* components, and thus into horizontal (i. e. thrusting and folding), and into vertical (i. e. sinking) movements. Dislocations may therefore be divided into two main groups, of which one is produced by the more or less horizontal, the other by the more or less vertical relative displacement of larger or smaller portions of the earth's crust.

There are large areas in which the first, and others in which the second group predominates, and there are also regions in which both groups appear together, and in which an intimate connexion may be recognized between them, the resolution of the movements in space having in these cases been less complete. This essential difference in the movements of the lithosphere may be clearly perceived from a comparative study of the structure of the Old World; nor has it escaped the notice of American geologists.

'The geological province of the Great Basin,' remarks Clarence King, 'has suffered two different types of dynamic action: one in which the chief factor was evidently tangential compression, which resulted in contraction and plication, presumably in post-Jurassic time: the other of strictly vertical action, presumably within the Tertiary, in which there are few evidences or traces of tangential compression[1].'

Our colleagues on the other side of the ocean have even gone a great deal further. After a comparison of the folded Appalachian mountains with the depressed Basin Ranges, Gilbert had in 1875 already suggested the possibility that in the Appalachians the causes of movement were *superficial*, in the Basin Ranges *deep-seated*[2]. We shall have an opportunity, when discussing the relation of the Alps to their northern foreland, of determining to what extent this supposition finds confirmation in Europe. We may however state at once that as a rule it is only the dislocations of the second group which are accompanied by volcanic eruptions.

These general considerations show clearly on what principles the terminology of orogenetic disturbances is based.

2 pl.; B. Lotti, Sopra una piega con rovesciamento degli strati paleoz., &c., Boll. Comit. geol. 1881, XII, pp. 85-96, pl. iii; by the same, La doppia piega d'Arni e la sezione travers. delle Alpe Apuane, loc. cit. pp. 419-428, pl. ix.

[1] Clarence King, U. S. Geological Exploration 40th Parallel, 4to, I, 1878, p. 744.

[2] G. K. Gilbert, in Wheeler, Report of Geological and Geographical Exploration and Surveys West of 100° Merid., 4to, III, 1875, p. 62.

A. *Dislocation by tangential movement.*

We will begin with those movements which are the result of tangential stress.

The simplest and most direct result of an approximately horizontal movement of the upper portions of the earth is the development of long *folds*, the crests of which extend for some distance, then gradually flatten out and are replaced by others which lie parallel to, and more or less

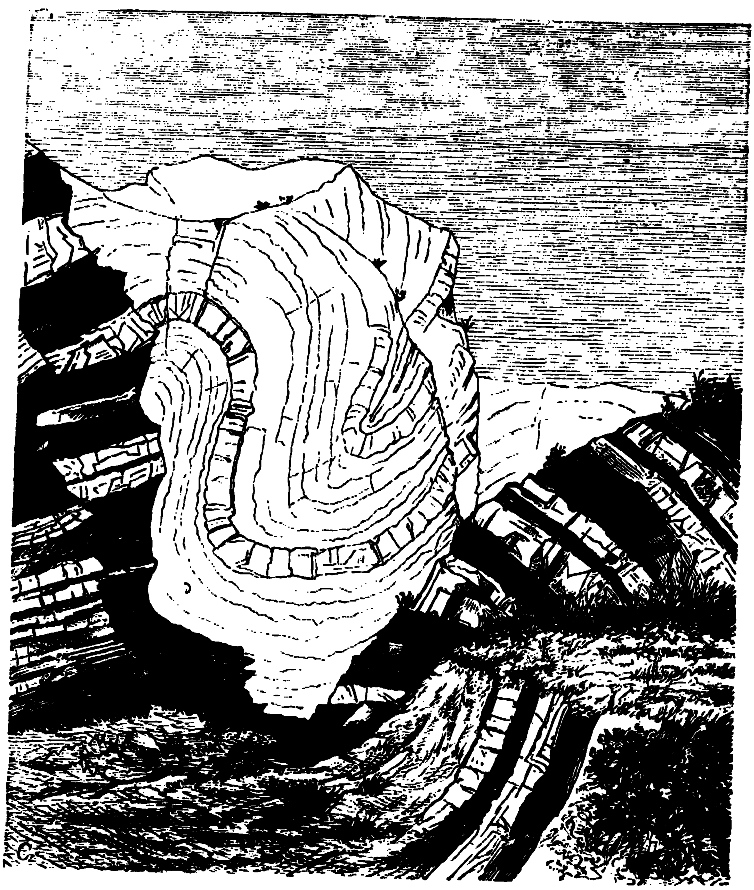


FIG. 7. *Folded menilite shales.* Wolfsgraben near Nikolschitz, Moravia.

alternating with them. Sometimes indeed a ridge bifurcates, its branches forming an acute angle. The folds are checked by opposing obstacles, and their strike then describes a curve with its convexity turned in the direction of the general movement. The central portion of the Jura is a long known and excellent example of this case.

Folding appears in the most diverse forms, in rocks of the most different kinds, and at various altitudes. In the banded menilite-bearing

shales which in Moravia accompany the outer border of the western end of the Carpathians, the folds present the regularity of a diagrammatic model. Those who have seen the cliffs of the Axenberg on the Lake of Lucerne will have viewed with astonishment the inextricable entanglement of the limestone beds. In the Himálaya, at heights which far exceed the highest peaks of the Alps, mighty folds also occur. In America the folded structure of the Appalachians, in its magnificent simplicity, gave rise to

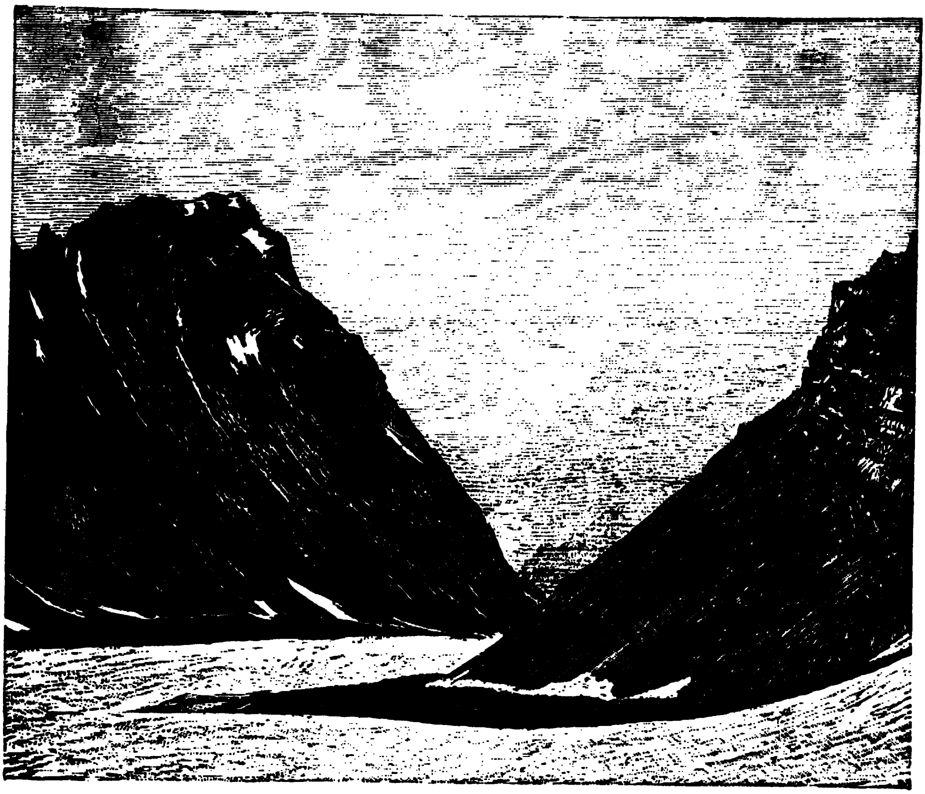


FIG. 8. *Reversed fold on the summit of the Mamrang Pass, Himálaya.* Reproduced from a photograph communicated by F. Stoliczka.

important treatises on mountain tectonics at a time when in Europe every considerable anticlinal ridge was regarded as an independent axis of elevation.

If the folding mass is bent back upon itself it rises in *broken anticlinals*, which may also be inclined one towards another. The examples described by Kauffmann on Pilatus, Escher on the Säntis, von Richthofen on Lake Formarin in the Vorarlberg, and by Lotti in the Apuan Alps, show various modifications of this structure.

It is quite true, as Heim remarks, that the same movement may give

rise to folds which are inclined in opposite directions—that in a chain in which the movement is towards the north, for instance, folds may occur, some of which are inclined to the north and others to the south; and it is no doubt equally true that the determining cause of the inclination of an anticlinal is the relative height of its two bases[1]. But observation shows, as was pointed out by Thurmann years ago in the Jura, and confirmed by Heim in many passages of his suggestive work, that the vast majority of inverted folds take one and the same direction, so that the top of the fold is directed outwards, the succeeding trough inwards; in the greater part of the Alps therefore the anticlinal is directed to the north, the synclinal to the south. This circumstance, too, explains the rule formulated by B. Studer, that the strata in the Swiss Alps, which

FIG. 9. *Summit of the Gstelli-Horn, mass of the Finster-Aarhorn,* seen from the Laucherli. Two bands of gneiss, one of which forms the summit of the Horn, and two bands of Jurassic limestone included in Trias.

are bent in a C-like form, turn the concave side outwards. The most imposing and most remarkable example of infolding and overfolding is afforded by the relations, so carefully described by Heim and Baltzer, of the Trias and the Jurassic limestone to the gneiss, on the northern slope of the Finster-Aarhorn mass[2].

The summit of the Jungfrau is composed for a height of 800 meters of overthrust gneiss; below this the precipitous cliffs on the northern side are formed of Jurassic limestone, which is squeezed into the gneiss in two great synclinal folds; below the cliffs of Jurassic limestone the gneiss again appears. The upper of the two Jurassic wedges penetrates, con-

[1] A. Heim, Der Mechanismus der Gebirgsbildung, 4to, 1878, I, p. 233, II, p. 207.

[2] Heim, loc. cit., and A. Baltzer, Der mechanische Contact von Gneiss und Kalk im Berner Oberland; Beitr. zur geol. Karte der Schweiz, XX, 4to, Bern, 1880, and Atlas.

tinually narrowing away, three kilometers deep into the mass of the gneiss; the lower wedge ends abruptly. This overfolding is continued eastwards with various modifications along the whole northern slope of this great mountain mass. Herr Baltzer had the kindness to conduct me from Hof, near Meyringen, to the Urbachsattel, beneath the Gstelli-Horn, where five inverted folds of gneiss, partly surrounded by the Trias, penetrate like wedges into the Jurassic limestone. The steep Gstelli-Horn, isolated by erosion, consists of a capping of gneiss, which forms part of the fifth or highest wedge; below this comes an infolded mass of Jurassic limestone, forming precipitous cliffs, and on the upper and lower limits of this Baltzer has found traces of Trias; then, beneath the cliffs, it is again composed of gneiss, which belongs to the fourth wedge. This section is wonderfully clear, and Baltzer's representation of it furnishes an excellent picture of the kneading together of the most resistant rocks, here presented to the eye in all its grandeur.

At the extremities of the long narrow folds of limestone, which are rightly regarded as 'rolled out' synclinals, the pressure exerted on the Jurassic limestone, together with the horizontal displacement, has attained the maximum degree. In such places it often happens that fragments of limestone, squeezed off from the main mass, may be met with isolated in the gneiss; and in the same way fragments of gneiss find their way into the limestone.

Here too, where the mechanical effect attains its maximum, we meet with that remarkable transformation of Jurassic limestone into marble, of which the mountain-making movements themselves are held to be the cause. The end of one of these limestone folds descends from the Laubstock to the Grimsel pass, and is there easily accessible to any one visiting the valley of the Hasli.

In all these extraordinary phenomena, especially in the rolling out of the limestone wedges, the forward movement of the arch-limb appears to have played the principal part.

Many years ago careful observers of the folding in the Jura mountains, such as Gressly, had perceived that in strongly inclined folds a tendency was present to divide along a plane corresponding to the axis of the saddle, and that when such a surface of division is produced, the upper limb is driven along over it. Similarly, H. D. Rogers, from an examination of the Appalachians, had succeeded in formulating the rule that in the case of a reversed fold the arched limb is shoved over the trough limb, that is to say, the uninverted side over the inverted side[1]. If the original fold is inclined to the north and the movement of the

[1] H. D. Rogers, On the Laws of Structure of the more Disturbed Zones of the Earth's Crust; Trans. Roy. Soc. Edinb., 1856, XXI, p. 442, Uninverted side of Wave usually pushed over the Inverted.

whole region is directed towards the north, then the surface of separation dips to the south.

It thus appears that in certain mountain regions this phenomenon occurs not merely in isolated instances, but is repeated in a whole series of parallel folds. The result is a very peculiar general structure. In the original, inclined, anticlinal fold the underlying portion showed the reversed, the overlying the normal succession of strata. But when, owing to overthrusting, the underlying, that is, the inverted flank, is completely concealed from observation, then only the uninverted flanks remain visible, lying in a series one behind the other and formed of beds dipping towards the interior of the chain—that is, in the case of a northern movement, towards the south—but in normal succession, so that, to make use of the method of symbolization employed by Albrecht Müller of Basel, we meet as we proceed towards the interior of the chain the following series of strata: a b c d e, a b c d e, a b c d e. A simply folded region would present the following series: a b c d e d c b a b c d e d c b a, &c.

This phenomenon we shall speak of as *imbricated structure* (Schuppenstructur).

Imbricated structure, as Bittner has shown, is developed with remarkable clearness in the eastern portions of the calcareous zone of the Alps, in Lower Austria. The long lines of strike have already assumed the north-easterly direction of the Carpathians, and the same succession of strata is repeated again and again, always with a dip to the south or south-east. 'The successive repetitions of the strata,' says Bittner, 'must be regarded as so many upper limbs of inclined or inverted folds, of which the anticlinal axes have been broken by the progressive development of the folds, in such a manner that the upper limbs have been shoved one over another, while the lower limbs each and all have been suppressed [1].'

The same structure, more or less clearly expressed, is to be met with in other parts of the eastern Alps, and it is repeated under peculiar conditions in the eastern Jura, precisely at that place where the resistance of the mass of the Black Forest was greatest. The regular folds of the Jura describe a broad crescent starting from the west and south-west. According to Albrecht Müller the influence of the Black Forest becomes evident on the east of a line drawn from the west side of its southern end past Kandern and Lörrach to the south, then from Basel eastwards, along the Birs, and following the western escarpment of the Gempen plateau towards Nunningen. To the east of this line there lies a zone of Jurassic deposits free from folding, which dip gently to the south and form as it were the southern shoulder of the Black Forest: this is the *table-Jura*. To the south of this table-Jura strikes the folded *chain-Jura*.

From Nunningen past Bretzwyl and Reigoldtswyl the northern part of

[1] A. Bittner, Die geolog. Verhältnisse von Hernstein, p. 305.

the chain-Jura, according to the same observer, is thrust over the table-Jura for a distance of from one to one and a half kilometers, and in particular the oolitic limestone of the middle Jurassic on to the upper Jurassic, which dips gently to the south, while to the south of this overthrusting, especially in the neighbourhood of the great tunnel of Hauenstein, three to four ridges of Muschelkalk appear, one after another, with a constant dip to the south [1].

The excellent works which Moesch has published on this part of the Jura mountains show very distinctly the gradual change of structure which takes place in the direction of the strike, that is, to the north-east. At Saalhöfen, below the Gaisfluh, to the east of Oltingen, and thence past Densbüren and as far as the Aare, the northern border of the chain-Jura everywhere appears as an anticlinal overfolded from south to north, and consequently lying with inverted strata on the margin of the table-Jura. The Miocene Molasse is thus wedged in as a long belt

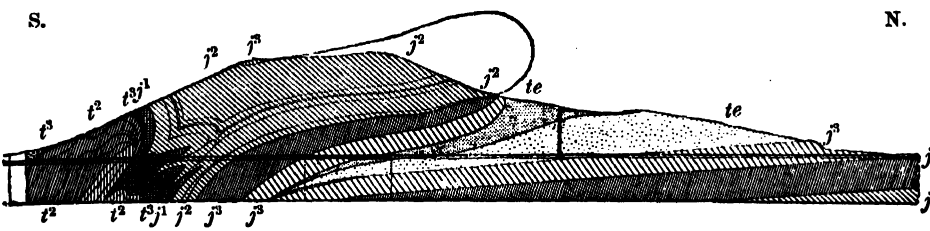



FIG. 10. *The Bötzberg Tunnel* (after Moesch). Pinching in of the Miocene beds between the overfolded chain-Jura and the flat table-Jura, which dips gently to the south.

$t^1$, $t^2$, $t^3$ = Trias formation; $j^1$, $j^2$, $j^3$ = Jurassic formation; *te*, *te* = infolded beds of Miocene.

between the anticlinal overfolded towards the north and the table-Jura which dips gently to the south.

The Bötzberg Tunnel traverses from the south the whole of the reversed folds of Trias and Jurassic, then enters the infolded zone of Miocene deposits, and through these finally reaches the flat-lying upper Jurassic beds of the table region [2].

[1] A. Müller, Ueber die anormalen Lagerungsverhältnisse im westlichen Basler Jura, pp. 428–462, and plate; cf. Studer, Geologie der Schweiz, II, p. 330; Moesch, Der südl. Aargauer Jura, Beitr. zur geol. Karte der Schweiz, X, 1874, pl. ii, fig. 3.

[2] C. Moesch, Der Aargauer Jura und die nördlichen Gebiete des Cantons Zürich; Beitr. zur geol. Karte der Schweiz, IV, 4to, 1867, in particular p. 266 et seq.; twenty sections on the border of the table and chain Jura; section of the Bötzberg Tunnel in the same supplement to Beitr. Heft IV (appeared with Heft X, 1874). Müller thought it necessary, in order to explain the imbricated structure, to assume in addition to pressure from the south, and resistance by the Schwarzwald, special parallel fractures, and in particular for the Wiesenberg-Mont Terrible chain and the Hasenhubel range, 'repeated shocks and rending open from below.' (In this matter, however, I adhere to the older view, represented at present in the most efficient manner by Moesch, according to which all these phenomena may be referred to overthrust folds.)

The overfolding of the northern border of the chain-Jura is continued beyond the Aare. The beds of Muschelkalk dipping to the south cross the river near Bad Schinzbach ($t^2$, Fig. 11), and then extend upwards to the summit of the Wülpelsberg, where their vertical edges bear the venerable ruins of the Habsburg. They contain Placodus and Myophoria; the tower of the ancient fortress stands on their highest ridge. Below the Muschelkalk, separated from it by a steep wooded slope, are some gypsum quarries in the Keuper ($t^3$, Fig. 11); this rests on dark lower Lias limestone. In the meadow-land below, loose blocks of Oolite are often met with, and still lower down, at the foot of the mountain, beds of upper Jurassic are disclosed to view, which, dipping sixty degrees to the south, support the whole of this series of strata [1].

While the overfolding of the northern margin thus persists, the folds in the interior of the chain-Jura gradually resume their normal position; this the innermost and most southern zone had not ceased to retain

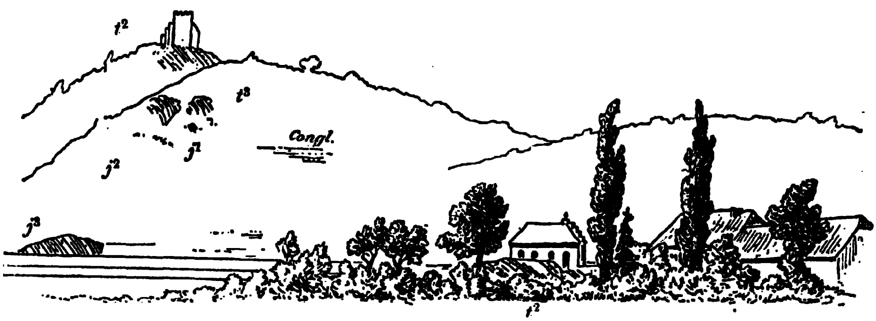



FIG. 11. *The Habsburg.* $t^2$ = Muschelkalk; $t^3$ = Keuper; $j^1, j^2, j^3$ = Jurassic formation.

even in that region where the imbricated structure was most strongly developed.

Thus, where the long folds of the Jura chains most closely approach the Black Forest, they show for a short interval the overthrusting of the upper limb, which is characteristic of imbricated structure; while beyond the obstructing region this phenomenon at once ceases. The northern border of the chain-Jura, however, still remains overthrust, while the inner does not quite abandon its regular folding even in the region of imbricated structure.

We shall again meet with this imbricated structure in South Tyrol and other places.

On comparing these phenomena with those observed by miners we see that they are none other than those cases of overthrusting which are

[1] This section has been repeatedly described, quite recently, for instance, in the Verhandl. Schweiz. Naturf.-Ges. zu Aarau, 1881, pp. 70, 71. I have not found the brown Jura and insect-marl *in situ*.

distinguished from faults under the name of *Wechsel* or *Schlächten* in Germany, and known in England as *creeps*.

It is to Köhler that we owe the application of modern views on the structure of mountains to explain the disturbances in the Carboniferous basin of Westphalia. The Coal measures of Westphalia have been folded by a horizontal force acting from south to north.

'By *Wechsel* or *overthrusting*,' says Köhler, 'we understand generally a disturbance where a seam lies higher on the hanging than on the lying side [of the fault].' . . . In Westphalia overthrusts *always* occur along the *strike*, and dip in the same direction as the displaced seams, but a little more strongly. The extent of the change in level of the seam amounts in one case to 500 meters. The thrust planes dip to the south, but there are exceptions which dip to the north. Overthrusts are nothing else than the 'highest power of a folding.'

Köhler then compares *Wechsel* with Heim's representations of overthrust mountain folds [1].

The united observations of Wimmer, Groddeck, Stelzner, and Köhler have established the fact that the famous ore deposit of the Rammelsberg near Goslar rests on a thrust plane of this kind, the Spirifer sandstone of the lower Devonian having been thrust over middle Devonian slates, and further that the peculiar form of the deposit is owing to the participation of the ore itself in the orogenetic movements. The disposition of the folds, the squeezing in and milling out of the bed of ore, which is sometimes reduced to a mere film, recall in every respect the imposing phenomena of the Finster-Aarhorn mass [2].

In some cases horizontal thrusting is so far developed, that fairly large masses of older beds, often even isolated by later erosion, are met with on younger formations. Among the greatest of such deviations from the normal position would appear to be the disturbances described by M. Bertrand on the outer border of the Jura between Besançon and Salins [3].

The regular strike of the mountain folds is sometimes interrupted by a sudden S-shaped curvature, and by the greater advance of one segment as compared with the others. Still more frequently a more or less vertical fracture occurs separating two portions of a chain at right angles to the strike. This dislocation of mountain segments relatively to one another is doubtless produced by an unequal movement of the contiguous masses, and it sometimes happens that the folds

[1] Köhler, loc. cit., pp. 199, 200.

[2] Köhler, Die Störungen im Rammelsberger Erzlager bei Goslar; Zeitschr. für Berg-, Hütten- u. Salinenwesen, 1882, XXX, pp. 31–43 and 278; 4 pl.

[3] M. Bertrand, Failles de la lisière du Jura entre Besançon et Salins; Bull. Soc. géol. de Fr., 1882, 3e sér., X, pp. 114–126.

on one side of the dividing plane are more crowded together, and show a greater tendency to form overfolds than those on the other.

These surfaces of separation have a most important bearing on the origin of folded mountain chains.

Escher, of noble and undying memory, when explaining to me in 1854 the folded structure of the Säntis, pointed with particular emphasis to a little face of rock in the neighbourhood of Wildkirchli, which appeared to form part of a fissure cutting transversely across the folds. When in 1857 he described the six folds of the Säntis before the Helvetian Society of Natural Sciences at Trogen he said: 'Whereas in the longitudinal direction of this chain no faults occur, on the other hand fissures transverse to it may be observed, which often traverse the whole mountain chain, as for instance that from Wildkirchlein to the valley of the Rhine. In these transverse clefts the polishing of the fractured surfaces, as well as their dislocation, may be observed.'

Escher also made the following entry in his notebook when visiting the Rasenäuli: 'The Valangien (near the Bogarten-Furkeli), as well as the Neocomian, presents a number of horizontal glide-surfaces; and it is extremely probable that this ridge, with its slickensides, is merely a part of a long fault running north and south, on the course of which the Wildkirchlein-Bommer fault, the little Stifelpass, and the Krinnenpass (Fählen-Saxerweg) also lie [1].'

Let us emphasize the following points in this first example: the strike towards the north (slightly to the west), at right angles to the direction of all the folds, the great length of the line and the horizontal striation of the slickensides; these are the three fundamental characters of all surfaces of this kind.

Jaccard's works on the Jura of the Vaud and Neuchâtel reveal the presence of a much more important transverse line in this region. From the southern border of the chain, passing close to the north-eastern end of the Lac de Joux and thence northwards through Hôpitaux nearly as far as Pontarlier, a disturbance is visible in the course of the folds of the Jura; this is most violent in the south, and seems to disappear towards the north. It is characterized in the south by the occurrence of short chains running north and south: Jaccard, in 1869, was uncertain whether these were to be regarded as independent chains, or merely as the deflected extremities of the folds lying to the west of the disturbance. Further observation has established the latter view as correct; on this great line of dislocation, therefore, which runs north and south, the inner folds of the Jura have been *dragged along at right angles to the strike.*

[1] A. Escher v. d. Linth, Geologische Beschreibung d. Sentis-Gruppe (edited by Moesch); Beitr. zur geol. Karte der Schweiz, 1878, XIII, pp. 71, 231.

The eastern portion of the chain has advanced further to the north than the western.

At Säntis the folds strike to the north-east, the transverse fissure to the north and slightly west; here too the folds strike to the north-east, the transverse line to the north. A second long line is said to occur to the west of the preceding, running from Les Tuffes and La Chaille (south of the little Lac des Rousses) a long distance in the direction of Salins, that is to say, more towards the north-north-west, but I possess no further information regarding it[1].

Studer's observations on the dislocation which occurs perpendicularly to the direction of the chains in the neighbourhood of the upper part of the Lake of Thun I have already mentioned elsewhere, as well as the relative dislocation of several portions of the Molasse, which Kauffmann has pointed out between the Lakes of Thun and Zürich[2].

In the eastern Alps numerous surfaces of dislocation occur, which, whatever may be the strike of the chain in question, are always directed towards the north or north-east, or more generally to the north-north-east. These surfaces are steeply inclined, and their dip appears to be as variable as their strike is constant, since it easily passes from west-north-west to east-south-east. The surfaces themselves are often embossed, yet smoothly polished, and not infrequently covered with striations or furrows, which run horizontally or nearly so; at the same time there is a tendency, so often observed in the formation of 'mirrors' of this kind, to the detachment of little wedge-shaped or lentiform fragments. In limestones the walls are sometimes entirely composed of loosely connected polyhedral fragments produced by the complete crushing of the rock during the movement; the polished face extends over all these fragments. In shales and hard marls the crushing of the rock or the development of a network of polished and striated surfaces within its mass is carried still further, and that peculiar form of brecciation is produced which is known in the Harz by the name of 'Verruschelung.'

Let us now proceed from Berchtesgaden to the south, and visit first the Königssee. At the point where the Falkensteiner Wand projects furthest into the lake, a large smooth perpendicular wall of limestone occurs, running north-north-east, with a number of parallel fissures in the mass of the rock. If on the other side of the lake we ascend the mighty limestone mass of the Steinerne Meer, we shall repeatedly meet during the ascent with surfaces striking to the north-north-east, as for example near the spring in the Saugasse, and again on the plateau of the Steinerne Meer itself, in the narrow pass above the Funtensee Alp.

[1] A. Jaccard, Jura Vaudois et Neuchâtelois; Beitr. zur geol. Karte der Schweiz, 1869, VI, pp. 263, 264.

[2] Entstehung der Alpen, p. 61 et seq.

The whole mass of the Schönfeldspitze, with its upturned beds, gives the impression of a segment of a fold compressed between the north and north-north-eastern clefts. At the Buchlauer Scharte we reach the edge of the southern scarp, and at the same time the southern limit of the limestone belt. The eastern side of the Scharte is formed by large faces, constantly directed to the north-north-east, which break up the mighty precipice into a number of great subdivisions, projecting like buttresses or the side wings of a theatre, in precisely the same fashion as in the case of the southern scarp of the Dachstein mountains, in the valley of the Enns.

On the Buchlauer Scharte we are surrounded by sheer walls of greyish-white limestone; far below them spreads an undulating fertile region of hills. This is the schistose Palaeozoic region of the Mitter-Pinzgau; it extends to a great distance in the direction of Zell and Taxenbach before it rises to heights of any importance; behind these appears the jagged crest of the Tauern.

Let us cross this region of schists.

In the gneiss of the Tauern those gold-bearing veins ('Gangstreichen') occur from which the 'Gold of the Taurisci' was derived, and which for many centuries supported rich and famous mines. These gold-bearing fissures or flaws are very numerous and with rare exceptions strike to the north-north-east, or north-east; sometimes they cross each other like the meshes of a net. Two zones or sheaves of these flaws are particularly worthy of note, one on the line of the Rathhausberg, which is 1,700 meters long and strikes to the north-north-east, and another on the line Erzweise-Bockhardt-Siglitz, which strikes slightly more to the east, and with its southern continuation on the other side of the glacier may be followed for a distance of seven kilometers. In a vertical direction these flaws have been traced over a distance of 1,500 meters.

A most detailed description of them has lately been given by F. Posepny. This observer regards flaws as the result of local inequalities in the horizontal movement of the different parts of the mass: 'This process tended not so much to produce a *fissure* or a rent, as a *displacement* of the solid medium.' The fissures generated in this way are neither precisely rectilinear nor quite plane, but crooked or with undulating surfaces. At the places where they bulge out the horizontal movement gives rise to the friction-breccias which accompany the flaws, and fill in the space between their slickenslided surfaces. In the neighbourhood of the Bockhardt the flaws extend also into the limestone [1].

Let us leave this region, instructive though it is in detail, and proceed further south to the mountains which lie near Raibl. An imposing and clearly marked series of Trias deposits occurs here. It inclines regularly

[1] F. Posepny, Die Goldbergbaue der Hohen Tauern (aus dem Archiv f. prakt. Geol., I), 1879, pp. 21, 92, 218, et passim.

towards the south. One of its stages, the ore-bearing limestone, which forms the entire mass of the Königsberg, contains deposits of galena and calamine; black shales, containing fish remains, cover the ore-bearing limestone.

Posepny has also published a monograph on this locality, in which he shows that the galena occurs in a series of flaws or clefts, which strike almost directly northwards, and are united in zones. These fractures, says Posepny, may be compared to delicate incisions in the rock; and it is but seldom that they develop into actual fissures, which are in part open, in part filled with the débris resulting from friction. The walls are as a rule smooth, but are sometimes covered with parallel grooves, sometimes by intersecting systems of striae. The dip varies, being now directed to the east, now again to the west; but where to the south these fissures cross the limit of the superposed shales, it is plain that these shales have been dragged, and that the whole district has been displaced along the flaws. The ore-bearing limestone thus advances towards the shales by jerks as it were, and from the exposures in the mines as well as at the surface, Posepny has been able to show that on the west side of the valley the sum of the successive displacements, towards the shales, amounts to about 420 meters, but on the eastern side, where the conditions are not so clear, to about 760 meters. The displacements occur in such a way that at the bottom of the valley, which likewise runs north and south, the limestone advances furthest towards the south, but on the two sides it retreats with each dislocation further to the north [1].

Let us now leave Raibl and visit the valley of the Lahn, which lies parallel to it on the east. Here we find a much more important horizontal displacement. The west side of the valley corresponds very nearly to the prolongation of the mountains of Raibl; then follows a line of discontinuity, running to the north or north-north-east, which corresponds to the main valley, and to the left main branch of its fork to the south, with a possible continuation thence through the deep defile to the east of the Mittagskogel into the valley of the Coritenza; all that lies to the east of this line, the mass of the Prinza, of the Mangart, the Jelouz, and others, is shifted about three to four kilometers towards the north [2].

A number of examples might be quoted from the eastern Alps, but it will suffice to recall the line of dislocation of Belluno, which likewise

[1] F. Posepny, Die Blei- und Galmei-Erzlagerstätten von Raibl in Kärnten; Jahrb. geol. Reichsanst., 1873, XXIII, p. 325 et seq. The undulating surface of the 'Morgenblatt' is, as the director of this mine, Hr. Gröger, informs me, known for 500 meters in a vertical direction; the three chief groups of flaws, Josefi, Struggl, and Morgenblatt, strike north to north-north-east, and the ore-bearing flaws are accompanied by a number of 'dead' flaws. The calamine beds are distinct and end suddenly in the Galmei-Kluft which strikes to the north-north-west.

[2] Jahrb. geol. Reichsanst., 1867, XVII, p. 576.

strikes to the north-north-east, and which we considered when discussing the earthquake of Belluno.

In the north-eastern portion of the Alps these flaws, which have hitherto been so constantly directed to the north, north-north-east, or north-east, experience a deflection. At the Hohe-Wand, near Wiener-Neustadt, where the Trias limestone overlies Cretaceous beds, both, as Bittner has shown, are intersected by planes striking to the north-north-west, along which they are shifted[1]. This instructive intersection of disturbances will be discussed later.

In the eastern Alps the effects of these vertical planes of dislocation on mountain structure may be followed in every stage, from the dislocation of great mountain segments on both sides of a transverse valley down to the displacement along an ore-bearing flaw, only a few meters in amount, or finally to divisional planes in the limestone, which appear as simple cracks no wider than a hair; and these last appear to play a similar part in the mountains to that of the far smaller glide planes which the microscope reveals in contorted rocks[2].

Examples are not wanting in other regions; the Medina fault along which one half of the Isle of Wight has been displaced against the other is an instructive case. That these surfaces, as well as the thrust planes, are the result of tangential stress, needs no further proof; they possess no distinctive name.

Köhler has also observed dislocations of this kind in the Coal-measures and classes them with Carnall's *Uebersprünge*. I shall in speaking of them employ the term *Blatt*, an expression borrowed from the miners in the Alps[3].

The tangential movement in the earth's surface thus produces two distinct types of surfaces of discontinuity. The first group corresponds to *overthrust planes*, 'Wechsel' or 'Schlächten,' the repetition of which gives rise to imbricated structure, and the second group comprises *shift planes*, 'Blätter' [flaws] or 'Uebersprünge.'

The strike of the overthrusts coincides with the strike of the folds and is deflected along with them. The strike of the flaws is more or less, but not always precisely, at right angles to the strike of the folds; it is not subject to deflection like that of the overthrusts, and probably indicates more correctly the general movements of the mass.

Every thrust plane has its definite dip, which is continued in the same direction downwards. The inclination of the flaws is almost always very steep, but may change from one direction to its opposite and return again to the first in following the same downward course.

[1] Bittner, Hernstein, p. 245 et seq.

[2] A. Heim, Mechanismus der Gebirgsbildung, pl. xv, fig. 8.

[3] [This has been rendered 'flaw' in the translation, a word which, like the feature itself, has some fellowship with 'fault.'—*Note by Editor.*]

Flaws far more than overthrusts contribute to the formation of valleys. Flaws are sometimes metalliferous, overthrusts much more rarely so.

In their normal form flaws are produced by a movement of two adjacent portions of the earth's crust in the same direction, but to an unequal extent. The parallelism of the movement of the two parts is often only present as regards direction, the dip of the beds being much steeper on one side than on the other. This is particularly the case when, as the result of a more violent movement, the portion in advance is more intensely folded. Considerable differences in level may thus occur in a flaw without subsidence of either of the two wings or the formation of a fault in the proper sense of the term, and it is characteristic that in this case no vertical striations are visible on the slickensides, but that the lines on the latter are only gently inclined to the horizon; or else two systems of lines are visible, one over the other, of different but gentle inclination.

An incomparably greater complication of all these relations, as well as of flaws and of overthrusts, occurs when two folding movements in different directions succeed one another in the same region.

In the greater part of Europe, north of the Alps, the mountain chains show folding towards the north, as in the Alpine system itself. This however does not exclude the existence in Central Europe of two different directions, which have produced folds and mountain chains striking more to the north-east in the one case, in the other more to the north-west. The former is known as the *direction* of the *Netherlands*, the latter as the *Hercynian direction.*

In regions where only one of these two directions finds expression, as in the south-west of Ireland, where in the mountains around the Lake of Killarney the Devonian is thrust high over the Carboniferous limestone [1], or in the coal-fields of Belgium, or in the Erzgebirge, the connexion of the dislocations and the movement of the earth's crust is more easily recognizable, however the relations may otherwise be complicated. The task is incomparably more difficult when two folding movements of different directions have exerted their influence on the same mountain chain.—

According to Lossen's extremely instructive description, the Harz must be regarded as a mountain knot, the result of a unilateral folding, which however took place first in the direction of the Netherlands, then in the Hercynian direction. We must thus assume first the action of a force from the south-east, under the influence of which the fundamental lines of the structure were produced; later on, when these main lines, which may still be recognized in the strike of a large portion of the chain, were already present, and when in particular the granite mass of the Brocken already lay with its broad undulating surface beneath the

[1] E. Hull, The Physical Geology and Geography of Ireland, 8vo, 1878, p. 135, fig. 17.

Palaeozoic schist and quartzite, a force in the Hercynian direction, i. e. from the south-west, was exerted on this mountain range, the strike of which was already more or less to the north-east [1].

The axes of the folds and the thrust planes were frequently bent in a torsional curve by this second movement. The development of that great and remarkable system of veins which originates in the neighbourhood of St. Andreasberg, thus not far from the southern extremity of the granite mass of the Brocken, and the radial arrangement of which has been pointed out by Groddeck, is held by Lossen to be connected with these processes of mountain formation and to result from the torsion of the mountain mass [2].

Daubrée has experimented by subjecting ribbon-shaped strips of strong glass, with their narrow ends fixed in cheek-pieces, to a spiral torsion amounting to 20°. Radial sheaves of fissures were then seen to have been produced at regular intervals from the right and left edges of the plate [3].

The fissures in the Harz, some of which attain a length of 14 kilometers, have arisen under quite different conditions. The edges of the plate, which in Daubrée's experiment determine the arrangement of the fissures in the glass, are not present in nature; moreover, and this is an essential point, while Daubrée subjected his plates to actual spiral torsion, in nature the two movements at right angles to one another took place, one earlier, the other later, and neither of these was in itself torsional. Nevertheless, there is in fact a certain resemblance between the system of veins radiating from St. Andreasberg and the sheaves of torsional fissures produced by artificial means.

Kayser's investigations have completed our knowledge of this system of fissures in more than one essential point. He shows that each of the larger fissures is accompanied by a dislocation in a horizontal and in a vertical direction, and that these dislocations affect also the granite, which is displaced along the fractures in the same way as the other rocks.

The principal lines of fracture are: the fissure of the Oder, that of the Acker, and the sheaf of fissures of St. Andreasberg.

The fissure of the Oder, about 14 kilometers long, runs to the north-north-west, starting from a point to the east of St. Andreasberg and intersecting at right angles the strike of the folds which follow the direction of the Netherlands: its plane is inclined to the east, and its eastern side is moved towards the north and downwards. To the east of this great line a number of fissures occur, striking to the north-west and

[1] K. A. Lossen, Ueber den Zusammenhang zwischen Falten, Spalten, und Eruptivgesteinen im Harz; Jahrb. k. preuss. geol. Landesanstalt, II, 1882, pp. 1–50.

[2] A. v. Groddeck, Beitr. zur Geogn. des Oberharzes, Zeitschr. deutsch. geol. Ges., 1877, XXIX, p. 440 et seq.; Lossen, loc. cit., p. 38.

[3] A. Daubrée, Études synthét. de géol. expérimentale, 8vo, 1879, in particular pl. ii.

terminating on the line in an acute angle; the eastern side of the most southerly of these is displaced considerably towards the north (Fig. 12, 4).

The fissure of the Acker begins near the point of origin of the Oder fissure, and its course is at first directed to the north-west; later on its strike turns more and more to the west-north-west, so that its distance from the Oder fissure increases. Along this line, as well as on another fissure running parallel to it on the north, a very obvious displacement occurs of the eastern side towards the north, and further on and corresponding to this, of the northern side towards the west: owing to the alteration

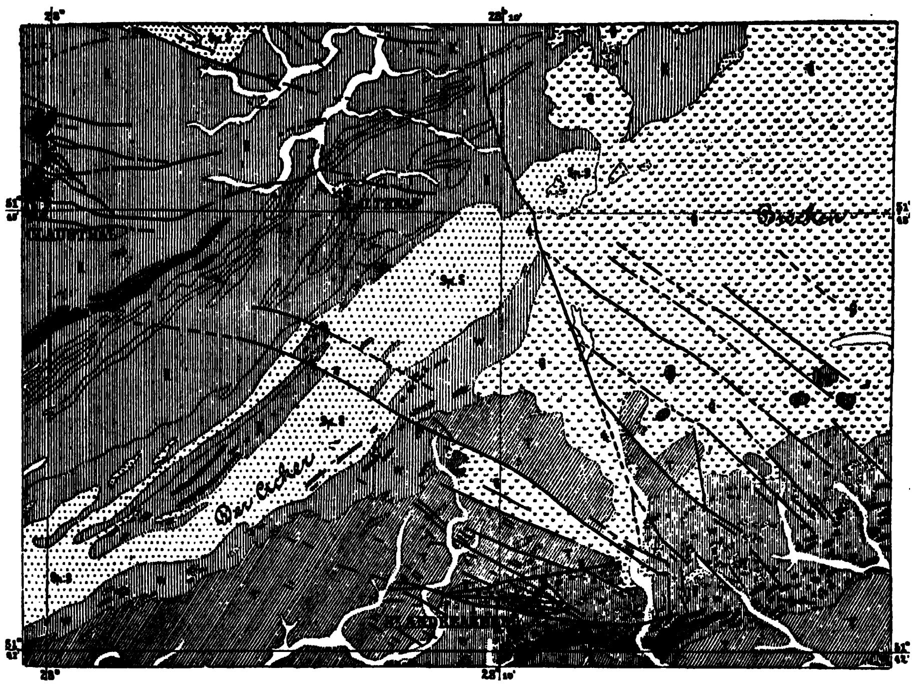


FIG. 12. *The system of fractures of St. Andreasberg* (after Lossen and Kayser). T = Grauwacke of Tann; W = Schists of Wiede; Sp. S = Spirifer Sandstone; K = Culm; G = Granite; D = Diabase. 1. Edelleuter Ruschel; 2. Neufanger Ruschel; 3. Acker fissure; 4. Oder fissure.

of its strike this fissure constantly approaches the direction of the long and numerous Clausthal fissures, which lie in the open space between the fissure of the Oder and that of the Acker (Fig. 12, 3).

A little vein, near the Acker fissure on the south, over which the mines 'Segen Gottes' and 'Neues Glückauf' occur, trends towards the point from which the great veins radiate, and this, together with the Acker fissure, divides a long narrow strip of granite from the grauwacke, which lies to the north of the Acker fissure and to the south of the vein itself. I consider this line important, because along it, no longer the northern but the

southern side is thrown down, and because, according to Kayser, the cleft probably dips steeply to the south. Since the group of fissures (Ruscheln) which succeeds to the south is characterized by a southern hade and subsidence on the southern side, it would seem, according to the descriptions hitherto published, as though the narrow band of granite mentioned above really represented a 'horst,' from which the country descended on both sides in successive steps.

The 'Ruscheln' are broad fissures filled with crushed fragments which border on the north, west, and south, a wedge-shaped area in which the silver-bearing veins of Andreasberg occur. The productive veins do not extend beyond the 'Ruscheln'; their position with regard to the point of radiation may be seen from Fig. 12.

The north Neufanger Ruschel hades to the south, and its southern side is let down together with the ore-bearing region. The southern Ruscheln also dip steeply to the south, but there seems to be a difference of opinion as to whether the southern wing of the most southerly of the great Edelleuter Ruscheln is thrown down still further or whether it is a case of thrusting[1].

It is a very fortunate circumstance that such a delightful task, as the solution of the questions in terrestrial dynamics raised by the double folding and the radial arrangement of the fractures, may be undertaken in a region like the Harz, which is easily accessible, where important mines occur, conscientious and distinguished observers are at work, and all requisite apparatus at hand; here we may indeed hope that essential progress will be made towards the comprehension of mountain structure in general. For the present it may well suffice to recognize in the observations made to the east of the Acker fissure the indications of a great torsional structure, and we may certainly, as we have already said, find some resemblance between the radiation of the veins and Daubrée's sheaves of fractures. The predominance of a southern hade in the case of the fissures situated to the south of the Acker line is more difficult to reconcile with this comparison. If the Oder fissure occurred in the Alps isolated from its companions, it would probably be regarded as a normal flaw of the older system of the Netherlands. The constancy in the strike of the Alpine flaws stands in remarkable contrast to the behaviour of the other fractures. It may be regarded as certainly demonstrated that in the formation of fractures the granite of the Harz plays a perfectly passive part.

### B. *Dislocation by subsidence.*

The stresses produced by the contraction of the terrestrial mass show, as we have said, a tendency to resolve themselves into movements in

[1] E. Kayser, Ueber das Spaltensystem am Südwestabfalle des Brockenmassivs; Jahrb k. preuss. geol. Landesanstalt, 1882, II, pp. 412–454, pl. x, xi.

two different directions, one more or less tangential or horizontal, producing folding, splitting, or overthrusting, the other vertical, producing subsidence. We have, it is true, spoken above of flaws in which the striae on the slickensides produced by gliding were directed downwards, and along which considerable vertical dislocation may have taken place, yet the exciting and determining cause lay even in these cases in the horizontal component. It now seems expedient for the sake of clearness to interrupt the series of examples which we have hitherto discussed, in order to become acquainted with the extreme cases in the second group of dislocations, and from these to return gradually to those complicated disturbances in which both components were, or still are, active.

Observation teaches us not to speak of a radial tension, in so far as we are referring to those disturbances, which only affect the structure of the outer crust of the earth. There is, in the whole of the extensive group of dislocations which I will now attempt to discuss, *no trace of an active impulse from above downwards.* When tangential movement is absent, the existing dislocations may easily be explained by the yielding of the foundation and by the force of gravity. The phenomena we observe are only various forms of passive subsidence and collapse. The impression produced is that the radial component acts at a great depth, and that in this way spaces are created beneath an outer shell which permit large portions of the latter to subside into them.

This point of view is not new; we meet it under various forms in many of the more recent works on mountain structure; it is of great importance for the comprehension of the structure of the outer portion of the planet, but I cannot enter into a further explanation of it here, where my object is simply to determine the more definite grouping and terminology of dislocations.

The investigation of a single sunken area or of a single line of subsidence does not lead us far. So long as each fold in a mountain chain was considered separately and every anticlinal of the Jura mountains was regarded as though it were the result of an independent linear elevation, further insight into the nature of folding generally was impossible. Just as the folds of a great chain are arranged according to universal laws, and as each of these is dependent on the neighbouring folds and on the general structure of the chain, so in large areas we see lines of subsidence arranged in nets or systems which, taken together, indicate the position of a field of subsidence, and, like the folds of a mountain chain, are the effects of a common cause.

We may distinguish in a normal field of subsidence two principal directions followed by the faults, on which we base their division into *peripheral* and *radial* faults, designations introduced many years ago by Deffner for the faults in the Swabian Jura. In addition to these

there are *diagonal* faults, which are independent of any general law, and shorter subordinate *transverse* faults, which connect the main faults at right angles.

The most important group is that of the *peripheral* faults. They not only bound the area of subsidence in a broad curve or polygon, but they are repeated within this area in a more or less concentric fashion, sometimes indeed taking the direction of the chord of an arc, or intersecting the angles of the polygon, and not infrequently an extremely curious regularity may be observed in the horizontal intervals between the several successive zones of peripheral faults, as these are traced from the margin towards the middle of the field of subsidence.

Along each of these peripheral faults the side lying nearer the centre of the field is, with a very few exceptions, let down, so that the sum of the subsidences increases towards the centre, which is thus the lowest point of the area of subsidence. It may however sometimes happen that between any two peripheral faults a strip of country has sunk *too deep*, so that the outer side of the succeeding fault then appears as the upthrown side, and a slight compensation is effected. These strips which have sunk too deep we will call *troughs* or *trough-subsidences* (Gräben or Grabensenkungen, after an old expression used by miners). It sometimes happens that along a peripheral fault the extent of the subsidence gradually decreases, and at the same time at no great distance from it a second peripheral fracture begins parallel to the first and is continued with increasing subsidence, so that one fault replaces another, in the same way as the folds replace one another in the chain-Jura. An intermediate piece of country then remains suspended as it were between the two faults, and forms what Mojsisovics, in the great subsidence faults in the southern Alps, calls a *bridge*.

If the outer borders of two fields of subsidence approach each other so that a ridge is left between them, on both sides of which the two areas of depression descend more or less in the form of steps, then we have what we shall distinguish, making use again of a common mining word, as a *horst*, in this case a *horst of the first order*, as opposed to the subsidiary horsts which occur here and there between networks of fracture. As horsts of the first order we may mention for example the Schwarzwald, the Vosges, Morvan, and the Kaibab Plateau in Colorado. That subsidiary horsts may occur even on faults in folded ranges, so soon as these also are accompanied by vertical movement, has already been shown by the example of the Acker fissure near St. Andreasberg.

The *radial* faults are not nearly so regular in their mode of occurrence as the peripheral. They are developed best in subsided areas of moderate extent, where they intersect the peripheral faults, and thus produce trapeziform blocks which occasionally bear witness to an independent

oblique and abnormal movement, by which the regularity of the field of subsidence is locally disturbed. Towards the centre, where the radial lines begin to be crowded together, smaller wedge-shaped blocks are formed, and this general parcelling up of the ground produces in places fields of subsidence which are peculiar and differ locally; they may have now a round, now an irregularly indented outline, and their size may vary greatly within the same field of depression. As examples of such a collapse towards the middle of a subsiding area we may mention the Rieskessel, the Höhgau, and the Lipari Islands.

We have already pointed out how easily even very great faults of this kind, connected with vertical dislocations of thousands of feet, may remain concealed from observation, and how often artificial cuttings may reveal such disturbances in places where their presence had been previously unsuspected. It is consequently not surprising that our knowledge of a network of faults is usually very incomplete. Bohemia, which has been so thoroughly studied in other respects, is a striking example of this fact. No indication on the surface of the monotonous undulating land of Pržibram betrays the existence of the 'Lettenkluft,' that mighty plane of disturbance now exposed down to a depth of more than a thousand meters, which intersects the silver veins, and at the bottom of the mine again brings into view, beneath the azoic divisions of the Silurian, the foundation of granite on which they rest. The Lettenkluft strikes to the north-east, and it is the south-eastern side which must be regarded as having been let down [1].

It is furthermore extremely likely that the boundary between the granite and the azoic deposits, which a little to the south of the Lettenkluft runs along the surface almost in a straight line in a north-east direction, corresponds to a second and similar fault, and that the Lettenkluft and this granite boundary are only parts of a great group of faults striking to the north-east, some of which have lately been determined between Beraun and Prague by the valuable researches of Krejci and Helmhacker [2].

These faults lie parallel to the strike of the Silurian basin of Bohemia, which, according to the investigations of these observers, assumes more and more the appearance of a broad and complicated trough subsidence, rather than that of a simple synclinal as was previously held. This group of north-easterly faults is again only part of that great system of faults which traverses the whole of the Bohemian mass, and includes the

[1] F. Posepny, Ueber Dislocationen im Pržibramer Erzrevier; Jahrb. geol. Reichsanst., 1872, XII, pp. 229–234.

[2] J. Krejci and R. Helmhacker, Erläut. zur geol. Karte der Umgebungen von Prag; Archiv f. d. naturw. Landesdurchforschung von Böhmen, 1879, IV, in particular pp. 82–90; the same authors' Erläut. zur geol. Karte des Eisengebirges, op. cit., 1882, V, passim, adds essentially to our knowledge of the network of fissures in the south-east of Bohemia.

faults at the foot of the Erzgebirge, the successive parallel lines of subsidence at the foot of the Isergebirge and Riesengebirge, the sharply defined line running from Elbe-Teinitz towards the south-east, the line of the valley of the Moldau, running to the south from Prague, and many others. Professor Krejci has had the kindness to communicate to me a provisional sketch of these faults; their more exact determination is the grateful task reserved to our colleagues at Prague. Even at present however we already perceive that a very large portion of Bohemia, in particular the west, north, and east of the country, has been the scene of extensive subsidence, which has taken place along numerous surfaces of rupture owing to the yielding of the substratum. The theoretical distinction between peripheral and radial faults cannot, it is true, be applied in this case. The Archaean region of the south, although also traversed by faults, yet rises, in a tectonic rather than in an orographic sense, above the rest of the country; on the north-east and north-west the slopes of the Riesengebirge and of the Erzgebirge mark its limits.

The conceptions to which the more restricted areas of central Europe have given rise, cannot however be generally maintained in those regions in other parts of the world, where horizontally stratified plateaux are traversed by great faults for extraordinary distances; here the conception of peripheral lines seldom admits of application, that of radial lines more seldom still; intersection of the lines is rare and local collapse is consequently not known. Owing to the extraordinary length of these fractures not only does the subsidence vary in amount, but it occurs now on one side, now on the other of the same fault.

In order to show this contrast I choose the most remarkable example, namely, that system of faults which traverses the high tablelands of western Utah, of which Dutton has given so clear and instructive a description [1].

The Wahsatch mountains, which stretch along the eastern side of the great Salt Lake and of Lake Utah, do not extend nearly so far to the south as is generally represented on our maps, but terminate in the neighbourhood of Mount Nebo at about latitude 39° 45′ N.

The Wahsatch mountains are separated from the Salt Lake by a great fault running north and south, with a downthrow on the west. Towards the south this fault passes into two step-faults. Opposite the southern extremity of the range rises the mass of Mount Nebo, which is traversed by a fault running north and south, with a downthrow to the east. This may be regarded as a continuation of the faults, or of the parallel faults, by which the western side of the Wahsatch mountains is downthrown.

[1] C. E. Dutton, Report on the Geology of the High Plateaus of Utah, 4to, 1880, with Atlas, in particular pp. 25-54.

Between Mount Nebo and the Grand Cañon of Colorado lies a region formed of vast horizontally stratified masses which constitute the western border of the great Plateau of Colorado. The strata are for the greater part marine deposits, which extend from the Carboniferous to the Cretaceous, but in the latter the intercalation of leaf-bearing layers and even of true lacustrine beds becomes more and more noticeable towards the summit; then follow Tertiary lacustrine sediments, and finally extensive sheets of volcanic rock. The surface of these great masses lies, in many cases, 11,000 feet above the sea; they are bounded and traversed by great linear faults.

The disposition of the fault-lines is shown in Fig. 13, after Dutton[1], who has embodied in its southern portion the results of Powell and Gilbert. This arrangement may be compared to the resolution of the principal fault of the Wahsatch and Nebo into divergent branches; and as a consequence the Kaibab Plateau in the south assumes as a whole the position of a horst situated between the eastern and western Kaibab faults (6 and 7 on Fig. 13). The eastern lines may then be regarded as connected with the western portion of those peripheral lines along which, as will be seen later, the Colorado Plateau has subsided, while the western lines stand in the most complex relations to the chains of the Great Basin.

Great orographic blocks are, as we have said, bounded by these faults. The first of these blocks, the Wahsatch Plateau, rises to the south-east of Mount Nebo and the end of the Wahsatch mountains, between lat. 39° 30′ and 39° N. It is from the western side of this mass that the other lines of disturbance proceed, which diverge towards the south; the accession of fresh lines similarly disposed gives rise to that great sheaf of fissures which on the north trend more or less towards the western side of the Wahsatch Plateau; diverging from one another as they proceed southwards, they cross the Cañons of Colorado and are prolonged still further to the south. Their course nearly as far as the parallel of 35° 40′ is shown in Fig. 13.

For long distances these lines of disturbance are more or less sharply defined ʃ-shaped bends in the strata, and are designated by American geologists, in contrast to the *folds*, that is to say the true folds of Alpine type, as *monoclinal flexures*. Since our nomenclature contains no equally convenient term for this form of disturbance I shall also call them *flexures*, as opposed to *folds*. In many places these flexures die away in continually flattening curves, in others they pass into a steeply inclined fracture with considerable subsidence of one side. Just as the fracture of an anticlinal fold gives rise to a thrust plane, so the broken *flexure* gives rise to a *fault* with *flexed* wings, the ends of the beds on the downthrown side being dragged upwards, on the upthrown side downwards.

[1] C. E. Dutton, op. cit., Atlas pl. iv.

Flexures and faults therefore are not to be regarded as essentially different phenomena. Both occur alternately along the same line of movement, according to the variation in the degree of the disturbance, and it may even happen that in the same place a disturbance appears at a higher level as a flexure, at a lower level as a fault. Furthermore, along these long

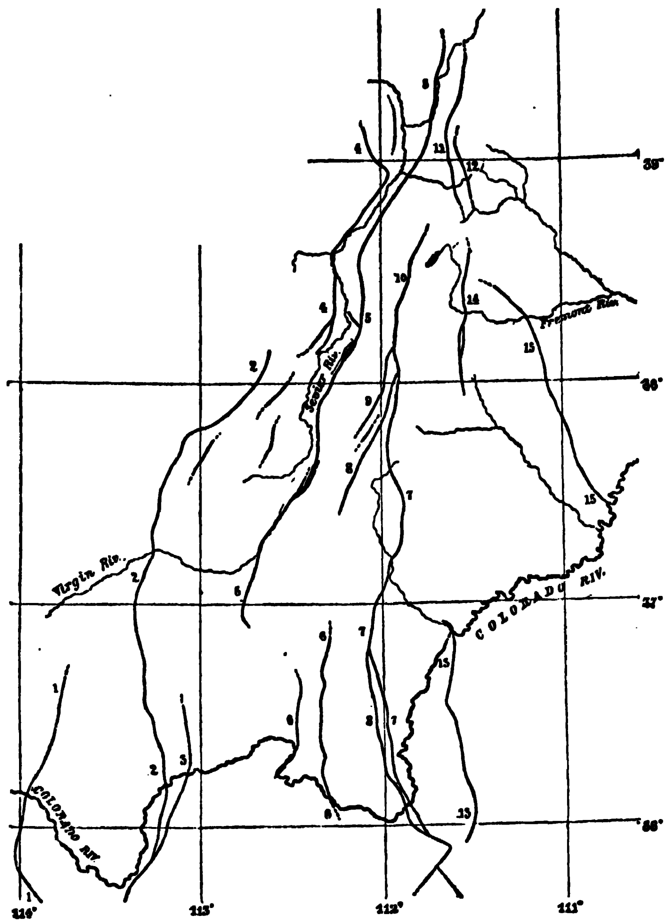



FIG. 18. *The faults of the High Plateaux of Utah* (after Dutton).

1. Grand Wash Fault.
2. Hurricane „
3. Toroweap „
4. Tushar „
5. Sevier „
6. West Kaibab Fault.
7. East Kaibab „
8. Paunsagunt „
9. Hayfield „
10. Awapa „
11. West Musinia Fault.
12. East Musinia „
13. Echo Cliff „
14. Thousand Lake „
15. Waterpocket Flexures.

lines not only does the amount of the depression vary, but the direction of its throw, sometimes the east, sometimes the west side being depressed, as we saw in the case of the principal fault of the Wahsatch mountains, and of Mount Nebo. This fact was pointed out many years ago by Élie de Beaumont, in his description of the fault of Saverne in the Vosges.

The following example will illustrate this point.

Let us follow from south to north the line of the Sevier, as represented by Dutton (Fig. 13, 5). It starts thirty-five miles to the north of the Grand Cañon. At first the dropped side is bent *downwards*, that is to say in an *opposite* direction to that usual in dragging, and the other side is horizontal. At a distance of five miles from the disturbance, the bending of the strata disappears; they become horizontal, and lie at the same height as in the other limb. Further to the north the disturbance splits up into two step-faults. Still further, on the border of the Paunsagunt Plateau, the downthrown west side is bent *upwards*, the other side is horizontal. Still further to the north two secondary faults arise on the downthrown side, producing an arrangement in steps. The fault again becomes single, but has lost in throw.

The extent of the depression near Hillsdale, still on the border of the Paunsagunt Plateau, in about 37° 40′ N., amounts only to 800 feet. This continues for about ten miles; over the next sixty miles a gradual increase occurs. In Panquitch Cañon, through which the river Sevier flows, lies a great eruptive centre, which renders the disturbance more difficult to trace; the main fault however forms the great cliff, which borders the plateau on the east.

In Circle Valley a branch is given off and returns again to the fault. Still further north, near East Fork Cañon (38° 5′–38° 10′ N.), the downthrown strata are bent upwards towards the fault, but broken off near the top, with a throw of 3,000 feet. The maximum of dislocation is reached near the Mormon village Monroe (38° 38′ N.), and thence the throw diminishes. Between Glenwood and Salina (between 38° 45′ and 38° 55′ N.) it appears to fall to zero, and then a complete reversal occurs. Throughout the whole distance it has hitherto been the western side which was thrown, now the depression takes place on the east. The fault then forms the eastern border of the San Pete Plateau and continues to increase in importance until it reaches the neighbourhood of Mount Nebo.

Dutton believes that in this northern part of the fault the older movement was succeeded by a more recent one.

It has seemed to me necessary to enter into some detail in order to render more clearly intelligible the variations which occur along the length of this fault. Particular emphasis must be laid on the bending up of the strata contrary to the usual direction, at the southern end of the line of the Sevier. This behaviour is not uncommon, and may be explained by the fact that at the same place successive dislocations have been produced in opposite directions, so that first the eastern side, for example, and then the western was thrown down.

The amount of the vertical throw increases up to about 7,000 feet on some of these lines. As to the nature of the movement, i.e. whether the

lower side was depressed or the other elevated, American investigators without exception speak with the greatest reserve, and even expressly disclaim responsibility, should any more definite conclusion be drawn from the expressions they employ. In some special cases, however, as for instance those where trough subsidences, which are connected with secondary fragmentation, are concerned, Dutton expressly and emphatically points out that the orographic blocks have been let down. A striking example of this is presented by that strip of land which is described by Powell as 'the Musinia zone of diverse displacement,' and which is situated near the south-west edge of the Wahsatch Plateau between the West Musinia and East Musinia faults (Fig. 13, 11 and 12)[1].

The American geologists mention as a distinctive, indeed as the determining factor, in this form of structure the *complete absence of that*

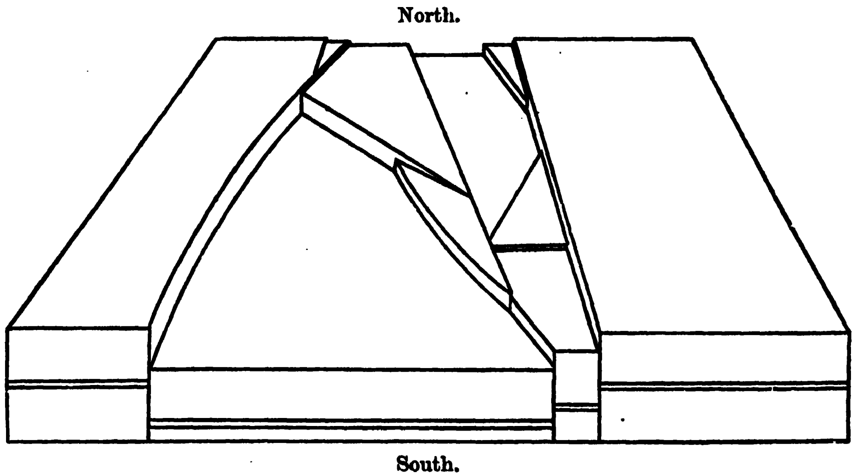



FIG. 14. Stereogram of a part of the '*Musinia zone of diverse displacement*' according to Gilbert and Powell (see Fig. 13, lines 11 and 12). The lowest horizontal line represents the sea-level; the double line corresponds to the upper parts of the Cretaceous system.

*force or pressure which acts in a horizontal direction and gives rise to mountain chains with Alpine characters.* Dutton even believes that the Musinia zone has been let down between two orographic blocks which were drawn *away from one another.*—

All these faults are of very recent date, some probably post-Quaternary: they all cut through the older Tertiary deposits of the region. Dutton has, however, found in a few places traces of an older system of flexures, which strike from the south-east beneath the Aquarius Plateau and which are younger than the Cretaceous and older than the Tertiary period[2].

These long faults which traverse regions composed of horizontal strata,

[1] J. W. Powell, Rep. on the Geol. of the East portion of the Uinta Mountains, 4to, 1876, p. 16; Dutton, High Plateaus, p. 34.

[2] Dutton, op. cit., p. 44.

are derived from flexures and present a variable throw, may be termed *tabular faults* (Tafelbrüche).

In addition to these typical tabular faults, there is a number of very important fractures, presenting very various characters, for each particular case of which it does not seem to me necessary to introduce special names. Examples of this kind are the Erythraean fractures, that is to say those of the Red Sea, the Jordan, and the coast-line of Syria, and then the volcanic lines of the west of South America. Each of these will be described later in such detail as the present state of our knowledge permits.

All the forms of subsidence which we have hitherto discussed have been connected with a system of linear flexures or fractures, along which the dislocation has been effected. There is, however, still another very important class of depressions, in which the subsidence appears to take place without any visible formation of linear fissures. A piece of the earth's crust, having irregular, sometimes rounded, sometimes elongated outlines, gives way and falls in; steep walls surround the resulting cavity, but no linear fissures appear to be formed. In certain cases indeed a straight line forms part of the contour; but this is owing to the subsidence having made use as it were of an older fissure; the separation has taken place along a cleft which already existed, and was not produced by the subsidence. Sometimes a cavity of this kind occurs isolated, and has a likeness to a caldron; sometimes it is too large and irregular for this designation to be applicable. The periphery of these regions of collapse may be elongated parallel to the strike of the beds, but the inbreak takes place independently of the nature of the ground. Finally it very often happens that a larger or smaller number of collapsed areas are grouped side by side, separated imperfectly by spurs, like horsts; or they may even be united together to form a single vast depression.

The inbreaks present also this peculiarity, that they appear in folded regions, that is to say in regions where those horizontal stresses are indicated, the absence of which is so striking in the Colorado Plateau; and we may further observe that they rarely occur towards the outer margin of the folded region, but are very frequent towards its inner side. Such at least is the case in the Alpine system.

The granite mass of the Schneekoppe and the Isergebirge occupies a similar position in the Riesengebirge to that of the so-called Central Masses in the Alps. If we ascend the mountains from the Bohemian side we first meet with a mantle of schist and gneiss, with a clearly defined outcrop. After crossing the granite we suddenly find ourselves at the edge of the steeply walled caldron of the *Hirschberg*. Dykes of porphyry intersect the mass of the Schneekoppe at right angles to the strike; at the edge of the caldron these also are broken off, and at

the bottom we find their downthrown prolongations. All observers agree in regarding the caldron of the Hirschberg as a sunken area. Its comparatively recent age has been demonstrated by Beyrich [1].

The most externally situated example of such a sunken area in the Alps is afforded by the Flysch zone near *Salzburg*. An easily recognizable band of richly fossiliferous greensand and ferruginous oolite of Eocene age, accompanied by Lithothamnium limestone, also Eocene, having sometimes a reef-like outcrop, strikes along the outermost margin of the mountains from Bavaria to the east-north-east; it then breaks off and reappears with the same strike on the other side of the Salzach near St. Pankraz, by the Wartburg near the Mattsee, and in other places. Within this extreme outer border the Flysch zone over its whole breadth, and most of the border along with it, is thrown down over an area extending as far as Salzach on the east, and up to the limestone walls of the Untersberg on the south. Thus this region is deprived of the wooded foot-hills, which elsewhere furnish the transition from the green plain to the abrupt scarps of the mountains; but it is this very contrast, so unexpected and unusual, which confers upon the site of Salzburg its incomparable charm, and produces at the same time that effect of imposing grandeur which is associated with the heights of the Stauffenberg and Untersberg.

A second example is the curious sunken area of the *Prättigau*, of which I shall have to speak in detail directly.

The subsidence of *Laibach*, with its extraordinarily irregular outline, interrupted and divided by a number of projecting cliffs, forms a third case.

A fourth example is the depression of *Vienna*. This advances almost as far towards the exterior as that of Salzburg, but affects, in addition to the Flysch, the whole breadth of the limestone zone. Its length in the direction of the strike of the mountains which here run to the north-east is much more considerable than its breadth.

The line of the thermal springs of Baden and Vöslau forms its boundary on the south-west, but several isolated hot springs also occur on its eastern border.

A renewed examination of the *eastern margin of the Alps*, where they meet the Hungarian plain, has confirmed me in the opinion that a connexion exists between this feature and the depression of the Vienna basin.

The Alps do not end here along a rectilinear fracture, nor do they die away in folds which are continued for a long distance beneath the plain, as is the case further to the south. On the contrary, the mountain-margin

[1] E. Beyrich, Ueber die Lagerung der Kreideformation im schles. Gebirge, Abhandl. Berl. Akad. Wiss., 1854, p. 69; also Kunth, Ueber die Kreidemulde bei Lähn in Niederschlesien, Zeitschr. deutsch. geol. Ges., 1863, XV, p. 743.

presents two great arc-shaped excisions which correspond to two areas of subsidence.

The boundary of the first of these depressions commences near the southern end of the Neusiedler-See with low hills of gneiss, and continues past Kobersdorf and Landsee towards Güns. Near Landsee a fairly large mass of basalt rises along the edge; basalt also occurs in the interior of the depression near Pullendorf.

The second area of subsidence is far more extensive. It stretches from the southern border of the mountain chain of Güns, formed of slate probably Devonian, in a wide curve as far as Graz, and from there to Marburg at the eastern end of the Bacher mountains. If coming from Güns, after crossing those numerous valleys, excavated in soft Tertiary beds, which run down from the Styrian mountains to the river Raab, the traveller arrives close to the western boundary of Hungary, then, if from the heights between Grobendorf and Ulberndorf above Stegersbach, for example, he turns his gaze to the south-west, a scene will meet his eye such as is seldom to be found in Alpine regions.

On the right the lofty and sombre Devonian mountains of Graz sweep backwards in a broad curve; behind them rise still higher ridges, composed of gneiss and ancient schist, which gradually disappear from view as they pursue their way to the south in the direction of the Kor Alp. In front of the mountains of Graz lies a bit of green plain, and then, in the very centre of the landscape and quite isolated, the great cubical mass of the Riegersberg, the remnant of a once much more extensive sheet of basaltic breccia and tuff. A little to the left of the perpendicular cliffs of the Riegersberg the contours of the trachytic mountains of Gleichenberg are visible. Still further to the left the landscape melts into the mist which broadens over the vast plain of Hungary.

Thus ends the main body of the Alps. There is no gradual sloping away, but a sudden breaking off, or rather an in-sinking along two circular arcs accompanied by volcanic eruptions; and there is no causal connexion at all to be perceived between the structure of the mountains and the course of the in-sinkings. The mountain chain of Güns rises like a horst between the two fields of subsidence.

The connexion between these two depressions and that of Vienna is revealed by the circumstance that the members of the middle Tertiary group which lie along the edges of the fracture are the same from Vienna as far as the Bacher. The first Mediterranean stage, to which the marine Molasse of Switzerland also belongs, extends from Bavaria along the margin of the Bohemian mass past Linz, Melk, Horn, &c.; it has never yet been found within the just-mentioned depressions, but it reappears, developed to a conspicuous extent, to the south of the Bacher mountains. The oldest stage which is represented within these depressions is that of

the lignite beds of Pittau and Eibiswald with the fauna of *Mastodon angustidens*. On these follow the marine deposits of the second Mediterranean stage with *Cerithium lignitarum*, *Pyrula cornuta*, and the West African *Tugonia anatina*, and these are finally succeeded by the whole manifold series of the younger Tertiary.

Thus the age of the three depressions of Vienna, Landsee, and Graz is known with a fair degree of precision, and we shall see that extensive areas of depression in Central Europe lying outside the Alps must also be assigned to approximately the same period of the Tertiary aera.

These subsidences indicate a yielding of the substratum beneath certain parts of the already folded Alps.

Still more striking than in the Alps is the caldron-like form of the in-sinkings on the inner side of the Apennines. Since I described, many years ago, the somewhat circular excision of these fractures in the folded region, I have had repeated opportunities of visiting several of them again. The result has been to confirm me in the views I originally held. The contour of the Gulf of Genoa must also be mentioned here; the Tuscan depression, more or less elongated in the direction of the strike of the chain and extending as far as the inner border of the eastern Flysch zone, presents many points of resemblance to the depression of Vienna. Just as, when coming from the west by rail—from Munich, for example—we find ourselves, after crossing the Flysch zone in Vienna, at the bottom of the Alpine depression, so when travelling by the railway between Bologna and Pistoja we find ourselves, after crossing the Flysch, in Florence, which lies in a depression of the Apennines, as Vienna in a depression of the Alps.

The circular form of these depressions becomes still clearer towards the south, as, for example, on the southern coast of the Bay of Naples to beyond Capri, in the Gulf of Salerno between Capri and Punta della Licosa, in the Gulf of Santa Eufemia between Cape Suvero and Cape Vaticano, finally in the Gulf of Gioja between Cape Vaticano and Scylla. The horsts run out into the sea in the form of promontories. What may be the depth of these subsidences we cannot tell, but we know that at least 1,500 feet of ash and tuff lie beneath the town of Naples. Naturally, in considering these subsidences, it is not the flattened curve of the coast-line which we must take into account, but the arc-like line described by the foot of the mountain slopes, which in its course from cape to cape runs to a greater or less extent inland. The peripheral seismic line of Calabria would appear to be nothing else than the first sketch of a fresh great subsidence of the same kind, which is in gradual course of preparation. Such may also have been the origin of the great arc-shaped cliff which encircles the Piano di Catania and Aetna, and extends from Monte Cieri above Taormina past Monte Sordo and Monte Gallina above

Nicosia, Castro Giovanni, Piazza, Caltagirone, and Vizzini as far as the coast between Syracuse and Noto.

The west of Italy is thus the seat of a long series of subsidences, which together produce the irregular gouging out of the Apennines, and the varied outline of the coast, so strangely in contrast to that on the east. Local subsidence of this kind can alone produce horsts, projecting transversely across the strike of the mountains like the long limestone ridge of Sorrento and Capri.

Similar inbreaks may, however, attain to far greater dimensions still. This is shown by the structure of many coasts which are steeply broken across the strike.

Let us consider, for example, the mountains of the *Crimea*. Pallas has already described the northern portion of the Black Sea as an area of subsidence. Many later observers, including Spratt, have adopted this view, basing it on the sudden descent of the sea bottom and the nature of the broken edges of the Tauride mountains. The depth of the sea to the north of a line from Cape Emineh to Cape Saritsch is in fact only 70–80 meters, while to the south of this line it suddenly increases to 1,000–1,800 meters, and in the middle of the western half of the Pontus Spratt has even found depths of more than 2,100 meters, or nearly double the height of the Tauride mountains of the Crimea [1].

In the same way Émil Favre, basing his conclusions on Albich's work, as well as on his own observations in the Caucasus and the Crimea, has proved the original continuity of these regions on the eastern side [2].

We may consider the Caucasus as composed of two unilateral chains, which have been pushed one against the other from the south-west. Great volcanos, Elbruz and Kasbeck, stand here, contrary to the usual rule, in the very heart of the mountains, but the great fractures and disturbances occur on the southern slope. In the northern chain Jurassic, Neocomian, and younger deposits dip conformably towards the north, while in the southern chain complete unconformity may be observed between the Jurassic and Neocomian; in the northern chain, moreover, the older Tertiary stage is, as it seems, wholly wanting.

According to Favre it is to the southern zone of the Caucasus that the Tauride mountains belong, and, indeed, in this fragment, which likewise dips to the north, the stratigraphical peculiarities of the Caucasus are repeated.

The Tauride mountains, a southward-pointing wedge-shaped fragment of the outer ranges of a great mountain chain, thus represent a portion of

[1] Spratt, Geology of Varna, Quart. Journ. Geol. Soc., 1856, XIII, p. 80.

[2] E. Favre, Rech. géol. dans la partie centr. de la chaîne du Caucase, 4to, 1875, p. 106; Étude stratigr. de la partie sud-ouest de la Crimée, 4to, 1877, pp. 66–72 (from the Mém. de la Soc. de Phys. et d'Hist. nat. de Genève).

the Caucasus, which has subsided on its inner side. Its wedge-shaped form is in accordance with its position as a horst standing between the eastern and the western in-sinkings of the Pontus.

I shall have occasion later to quote examples of such sunken areas on even a far grander scale.

### C. *Dislocations produced by subsidence and tangential movement combined.*

In those cases in which both subsidence and tangential movement have occurred, we have first to determine the relation of the strike of the main line of fracture to the direction of the force which has produced the folding. If the fracture is nearly at right angles to the direction of the folds—in other words, if it forms a transverse fault—the disturbance will probably, owing to the difference in the intensity of the folding of the two sides, resemble a more or less oblique movement along a flaw plane. If on the other hand the fracture is longitudinal, as is much more frequently the case, then we must determine whether the sunken portion lies towards the interior or exterior, as regards the direction of the folding force; whether, for example, in a chain folded towards the north, the southern or the northern portion has subsided.

If a folded chain is traversed by a longitudinal fracture of which the *inner* wing is depressed, then a tendency is frequently observed to *overfold the fracture in a direction entirely opposed to that of the normal folding*, and, as a consequence, the strata are not only turned up along the fracture, but may even be wedged in or overturned. This phenomenon we call folding backwards or *backfolding* (Rückfaltung).

Several excellent examples of backfolding occur in Central Europe.

The great mass of the *Riesengebirge* and *Isergebirge*, including the Heuscheuer, and the inner parts of the Sudetes, has been subjected to a movement directed from between north-east and east. On its inner side it is traversed for a long distance by a fracture striking to the north-west, and on this line granite and other Archaean rocks are driven to the south-west over Jurassic and Cretaceous, in a direction opposed to the normal structure of the chain. Von Dechen has lately collected data relative to this fracture in its course from Oberan near Meissen to Zittau, a distance of 127 kilometers. In some places the Cretaceous is simply turned up against the granite, in others there is genuine overthrusting of the Jurassic and Cretaceous on to the granite [1].

The same phenomenon recurs on the south-eastern border of the Bohemian mass, facing the Alps. Near *Voglar*, not far from Ortenburg in Bavaria, Egger and Gümbel have found the gneiss thrust over

[1] v. Dechen, Ueber grosse Dislocationen; Sitzungsber. niederrhein. Ges. f. Natur- und Heilkunde, 1881.

a symmetrical synclinal of upper Jurassic, and Ammon has shown that in this basin the Cretaceous formation also is pinched in. Thus the overthrust took place after the deposition of the Cretaceous [1].

The same is true with regard to the southern border of the *Teutoburger Wald.* In such cases, however, there is no doubt some difficulty in determining whether true faults or flexures have been overthrust; judging by the great extent of the throw the former seems much more probable.

The same phenomenon of backfolding is also met with in the sunken areas of the Alps.

E. von Mojsisovics has had the kindness to represent in Fig. 15 the collapsed area of the Prättigau, as it appears according to existing observations.

From this we see that the western extremity of the Cretaceous zone of the eastern Alps ends in the Rhaeticon, that the folds and thrust planes are bent at right angles and give rise to true imbricated structure, so that they finally strike north and south, as though a great horizontal dislocation had occurred between the eastern and western Alps, along the line of the Rhine, and as though the Rhaeticon had been dragged along horizontally. If we now ascend the Rhaeticon to the north and approach from its highest point the Scesa Plana, its precipitous escarpment on the south, we do not see, as is the case somewhat further to the east, mountains of older schist and above them crests covered with glaciers or crowned by peaks of gneiss; far below lies the fertile hill-land of the Prättigau, at first composed of Jurassic or Cretaceous formations of Helvetian type, just as they occur on the surface of the Säntis on the other side of the Rhine; then follows a great expanse of Flysch. To the east the fracture is also sharply defined, and a narrow selvage of Trias separates it from the mass of the Silvretta, which is composed of gneiss.

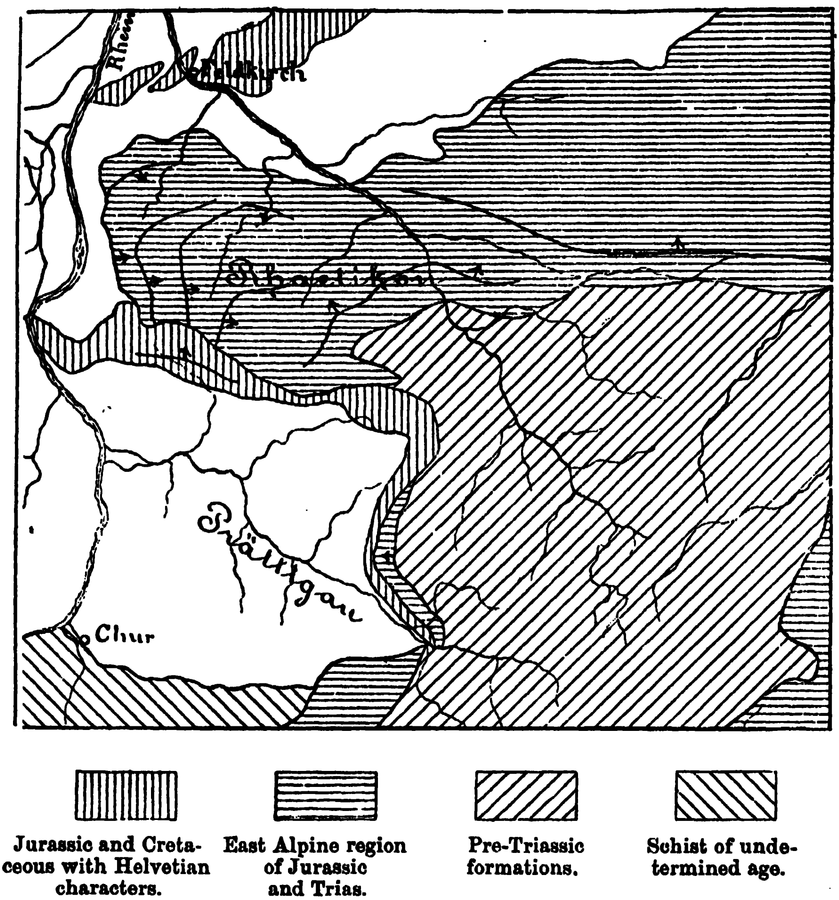
Thus in the Rhaeticon, where the folding towards the north or northwest has been so intense as to give rise to thrust planes and imbricated structure, we find nevertheless distinct backfolding on the southern border of the chain and partly also on the western border of the Silvretta, so that on the north and east the area of subsidence is surrounded in a more or less marked manner by this form of dislocation.

The *Hohe-Wand* near Wiener-Neustadt is a similar example of backfolding in an Alpine area of subsidence. We have already referred to the flaw plane which occurs in it, on page 120. This wall runs parallel with the line of thermal springs, in its immediate neighbourhood, and represents the most marked rupture of the eastern wing of the limestone Alps. Although, as has been shown by Bittner, the whole of this region

[1] L. v. Ammon, Die Jura-Ablagerungen zwischen Regensburg und Passau; Abhandl. zool.-miner. Ver., Regensburg, 1875, X, pp. 94–97.

is forced towards the north-west in clearly defined imbricated structure, yet we see the Trias riding along this internal fracture over the Cretaceous formation, in the opposite direction, namely to the south-east, and thus the formation of a great thrust plane is brought about.

That, however, which renders this spot particularly instructive is the circumstance, also pointed out by Bittner, that the whole mass, which is folded back and overthrust to the south-east, is cut through by flaws




The part left white to the east of the Rhine is covered by Eocene Flysch.

FIG. 15. *Prättigau and Rhaeticon* (according to a sketch very kindly communicated by E. v. Mojsisovics).

of more recent date, its displacement along these producing step-faults in very much the same way as in the limestone cliffs which form the southern limit of the Dachstein mountains, or the Steinerne Meer; and furthermore these flaws have the same direction as the not far distant Kamp-line—the existence of which was discovered by the observation of earthquakes. If now, however, in a folded region subsidence occurs

along longitudinal fractures, in such a way that an area situated on the outer border sinks down, so that, for example, in a region folding northwards the country lying to the north of the main region of folding subsides along east to west fractures, then *the horizontal movement becomes far greater, as if it had been assisted* by the subsidence. This we will call folding forwards or *forefolding.*

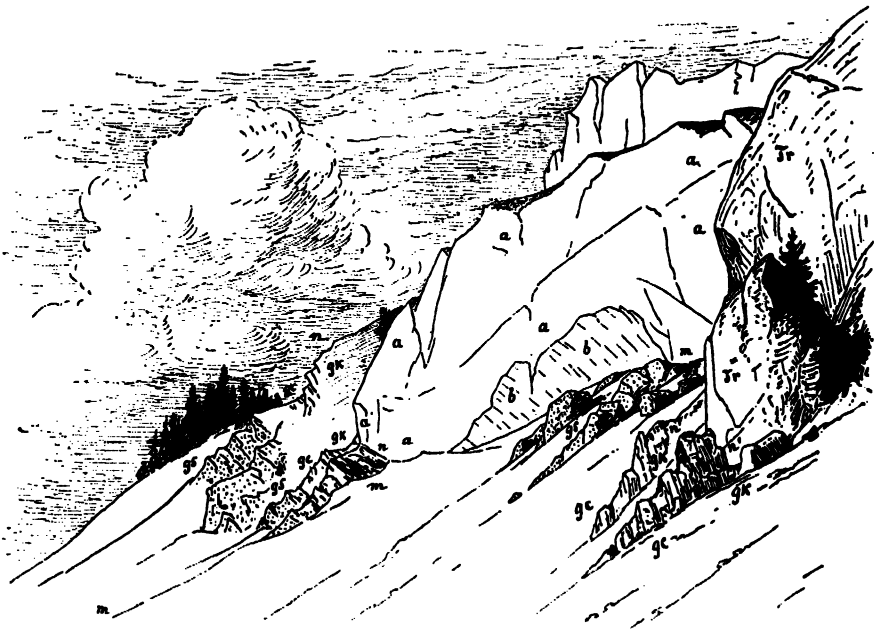



**Fig. 16.** *Foot of the Heiligenstein at the Hohe-Wand near Wiener-Neustadt* (Lower Austria).
*Tr* = Trias limestone; *gk* = Gosau limestone; *gc* = Gosau conglomerate; *gs* = Gosau sandstone; *n n*, *n′ n′* thrust plane between Trias and inverted Cretaceous; *m m m* line of dislocation on the flaw plane *a a a*; *b b* sheet of friction breccia on the face of the flaw.

Such appears to have been the process which has led to the complicated structure of the *coal-fields of Belgium.*

From the neighbourhood of Boulogne, to as far as Aix-la-Chapelle, the country is overfolded towards the north, so that in many places, in the Pas de Calais and near Liège for example, the Coal-measures are worked beneath the Devonian; and near Namur a downwards sloping fragment of a great anticlinal fold, consisting of Silurian and Devonian beds, rests on the Carboniferous, which also is bent downwards in the same direction.

These extraordinary disturbances lie hidden beneath the surface of a low hilly country, covered with Cretaceous beds, and their presence has only been revealed by extensive mining. By this we are enabled in the light of our present knowledge to make an analysis of the phenomena.

According to Cornet and Briart we have to distinguish near Namur: first, the formation by folding from the south of the Silurian Crête du Condroz, which gave rise to the difference between the Devonian deposits to the north and to the south of this ancient ridge; on this followed post-Carboniferous folding from the south, causing the first overfolding of the Coal-measures on to the ancient anticlinal; then the formation of a great east to west fracture, hading to the north, with downthrow of the northern side; this is the '*faille de Boussu*' (A A A, Fig. 17) which traverses the northern part of the folds along the strike, and throws down their northern side. Then follows a second fracture, the '*cran de retour d'Anzin*' (B B B, Fig. 17), nearly parallel to the strike of the first, but cutting it crosswise

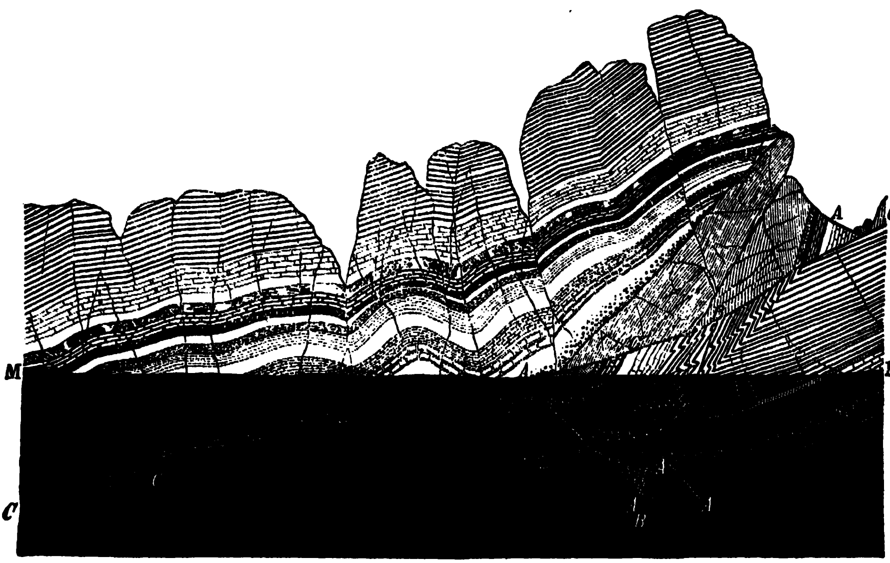



FIG. 17. *Processes in the Belgian coal-fields* (after Cornet and Briart). A A A, fault with downthrown northern side (*faille de Boussu*); B B B, fault with downthrown southern side (*cran de retour d'Anzin*); C C C, great thrust plane (*grande faille du Midi*); M M, existing surface and overlying Cretaceous.

with a hade to the south, and producing the downthrow of a very large part of the southern side, and a simultaneous throw of both sides of the '*faille de Boussu.*' These principal downthrows, which are accompanied by subsidiary movements, were followed by the thrusting of the whole of the southern complex towards the north, above the earlier fractures, and along a great thrust plane which traverses the whole extent of the coal-field; this is the '*grande faille du Midi*' or the '*faille Eifelienne*' (C C C, Fig. 17)[1].

The extraordinary extent of this movement is best seen from the

[1] F. L. Cornet et A. Briart, Sur le relief du sol en Belgique après les temps paléozoïques; Annal. Soc. géol. belg., 1877, IV, pp. 71-115, pl. vi-xi.

fact that the thickness of what remains of the Coal-measures, already diminished by denudation, is estimated at 2,100 meters; of the Carboniferous limestone and Devonian at about 2,500 meters; and that the overthrusting was already known in 1877 to extend over a distance of about 200 kilometers. Cornet and Briart have attempted to give an ideal reconstruction of the overthrust wing, shown in Fig. 17, in order to obtain some conception of the extent of the destruction and denudation which has taken place, no doubt simultaneously with the thrusting, and they estimate the height of the mass removed near Namur at 5,000–6,000 meters.

Gosselet, a most competent judge in these matters, says: 'The cause of the folding lies in the subsidence of the central parts of the basin and the relative elevation of the margin, accompanied by the gliding of the beds one over another. The subsidence itself is a consequence of the constant retreat of the earth's crust [1].'

In this general survey of dislocations, the distinction between the tangential and radial, or, in other words, between the folding and sinking movements, served us as a point of departure. Our last examples, and particularly the striking furtherance which the tangential movement receives from the simultaneous subsidence of the foreland, bring us back to an examination of the causal connexion existing between these two classes of movement. This inquiry can, however, only be founded on the comparison of very large portions of the earth's surface. We perceive from the examples already adduced, that in all these cases a certain tendency is present to *overthrust the subsidence.* This overthrusting takes place on a large scale where the subsidence lies in front of the normal direction of the folds, as in Belgium, where the subsidence lies in front of the folded region of the Ardennes; but neither is it absent when the subsidence lies towards the interior, in which case the movement may be locally reversed, as on the southern border of the Riesengebirge, or on the south-western border of the Bohemian mass near Voglarn, or in the Prättigau, or finally at the Hohe-Wand near Wiener-Neustadt.

[1] Gosselet, Sur la structure générale du bassin houiller franco-belge; Bull. Soc. géol. de Fr., 1879–1880, 3e sér., VIII, p. 505.

# *CHAPTER IV*

## VOLCANOS

Stages of denudation. Vesuvius and Monte Nuovo. Monte Venda. Laccolites. Palandocan and Dary-dagh. The Whin Sill. The Hebrides. Predazzo. The Fissure of the Banat. Syenite cicatrice of Brünn. Elk mountains and the Harz. Batholites; Drammen granite; Vosges; Erzgebirge. Maculae. Invagination. The denudation series.

The eruptions, the ash cones, and the lava flows of our volcanos are only slight and superficial indications of great processes which take place in the depths of the earth: of the nature of these processes, however, we have even now, in spite of the unwearied activity of so many investigators, no precise knowledge. To trace the various directions in which research has been prosecuted does not lie within our present task: but, taking the best known volcanos of the present day as a starting-point, we may at least attempt to follow as far as possible, by means of a series of appropriate examples, the gradual denudation and destruction of a volcanic mountain. This is one of the methods which, it was conceived, would lead to a knowledge of the lower part of the volcanic vent and of the abyssal phenomena; and many points have certainly been elucidated in this way. It is thus a *denudation series*, if I may so express myself, which I propose to determine.

I have already described in some detail (p. 52) the funnel or sand cones which are produced during earthquakes on clefts in alluvial ground. The sand cones formed on November 9, 1880, during the earthquake of Agram, in the district of the Save, were not much more than three decimeters in height. Many of these small cones were isolated, others stood on a common basis or were arranged together on a little linear fissure[1].

As regards the mechanical process of their formation these minute cones have a closer resemblance to our great volcanic mountains than at first sight we might be inclined to admit. Fissures are formed, and at certain points the stiff or fluid mass wells up from below; if the edges give way the flow is increased.

This train of events is repeated in the history of volcanos. A fissure is produced by subsidence or some other means; at some place where this widens out, or where it is crossed by a transverse cleft, the lava, tense with water-vapour, finds a way of escape, and wells forth.

[1] G. Pexidr, Beitr. zur Kenntniss der durch das Erdbeben vom 9. November 1880 hervorgebrachten Sandschlammauswürfe, 8vo, 1880.

This is followed by explosion and the emission of ashes and dust. An ash cone is piled up; the side of the cone is torn open, its lips give way, and a stream of molten rock spreads out at its foot; but in many cases this stream is absent. As a rule that is all. But it has already been observed, and Geikie has recently emphasized the point afresh, that the great sheets of lava, which are occasionally met with over areas of many square miles, have not been formed in this way, but by escape from fissures which were probably open throughout their length[1]. Such eruptions may doubtless have been increased by the subsidence of considerable portions of the earth's crust; as has been supposed in the case of the great outflows from the fissures of the high tablelands of Utah.

A comparison of the cones produced by the heaping up of ashes enables us to distinguish among them various types of formation, such as those of Vesuvius and Monte Nuovo; but if we are to obtain results of any value in this branch of study we must bear in mind that all attempts at too exact a classification must prove fallacious.

Mountains with a Somma and atrium, such as Vesuvius, form and consolidate in a peculiar manner. The framework of lava, which is concealed by the ash, has no doubt a most complicated structure. Every great lateral eruption in such a mountain gives rise first to a vertical eruptive dyke, which extends like a wall from the funnel to the exterior surface of the inner cone, that is to say, to the atrium; next to short flows which stream over the outer covering of the inner cone, and proceed directly from a series of mouths ranged along the eruptive dyke; then to a more or less closed atrial ring, which is produced by the spreading out of these flows in the valley of the atrium, and finally to the great free lava stream which issues from the fissure of the Somma and flows down the slope of the outer cone.

Since the great eruption which produced the funnel of the Somma other eruptions of a similar nature have often occurred in Vesuvius. During this interval the atrium, owing to the constant growth of the central cone, has been advancing further and further upwards along the walls of the Somma. More violent eruptions and temporary destruction have often interrupted this process, but nevertheless the final result has been the elevation of the atrium, and at the same time an increase of its diameter. The outflows, which have solidified in the atrium, have formed a series of rings growing successively larger, and these atrial rings, superposed on one another, form at present in the interior of the mountain a great conical basin, broadening upwards, which separates the central from the outer cone, and encloses all the later eruptive dykes of the central cone. These stand with their lower part

[1] A. Geikie, The Lava Fields of North-western Europe; Nature, Nov. 4, 1880, XXIII, pp. 3–5.

in the basin, vertical to the central funnel, and at the same time radiating from it.

Such a structure can of course only arise when frequent eruptions succeed each other from one and the same funnel. There is nothing similar to be seen in Monte Nuovo, or, indeed, anywhere in the Phlegraean Fields. A few lava flows are present in this region, and many centres of eruption: the tendency to displacement of the eruptive centres is most clearly marked. Monte Nuovo is only a ring-shaped heap of cinders and some scoria, with an exceedingly deep crater, extending downwards almost to the level of its outer foot, and thus not far above the level of the sea.

The contrast between Vesuvius and the Phlegraean Fields is thus very great, and is generally recognized. It lies not only in the different nature of the lava, but above all in the persistence of the funnel in Vesuvius, as opposed to the mobility of the centres of eruption in the Phlegraean Fields.

The cause of this must be sought in the nature of the fissures, and a comparison with the Lipari Islands may, as we shall see directly, throw some light on the subject.—

Let us see what takes place when a volcanic cone, such as we have just described, is exposed to the ravages of denudation. The ash is washed away; the rocky skeleton may be preserved in so far as it consists of vertical dykes; but the flows, which rest on ash, are destroyed. On the summit of the mountain the eruptive dykes stand out in relief radially arranged; while around its foot the foundation of the volcano is laid bare.

The remains of the crown and a portion of the base are now to be seen, but not the funnel. Such is the condition of *Monte Venda* in the Euganaean mountains near Padua.

Its structure and its rocks have often been described; the most complete account is by E. Reyer[1].

Let us first consider the foundation.

The lowest rock visible is a mass of oligoclase-trachyte exposed at its foot on the western side near Fontana Fredda. Above this and in immediate contact with it follow Tithonian beds with *Phylloceras* and *Terebratula diphya*, dipping gently to the north-west; for a distance of two to three feet from the trachyte they are converted into a pale granular marble, eight feet further up they are of a light bluish-grey

[1] E. Reyer, Die Euganäen, Bau und Geschichte eines Vulcans, 8vo, 1877; in addition particularly G. v. Rath, Geognostische Mittheil. über die euganäischen Berge bei Padua, Zeitschr. deutsch. geol. Ges., 1864, XVI, pp. 461-529, pl. xv, xvi; in this work, p. 520 et seq., there is a reprint of de Zigno's work on the same subject, in which the Jurassic and Neocomian deposits of Fontana Fredda are discussed.

colour, less marmorized, and contain fossils which may still be recognized; still higher up they display the usual knotty fibrous structure of the Tithonian deposits, but even at this distance the calcareous nodules are more or less marmorized. The oligoclase-trachyte has thus caused alteration from the surface of contact *upwards*, and must have been intruded laterally between the strata.

Above the Tithonian lie thick beds of Biancone with the characteristic fossils of the Neocomian, then a mass of quartz-trachyte, and above this probably Neocomian again; then follows the whole thickness of the Scaglia, representing the upper part of the Cretaceous system. The Scaglia includes at least two masses of trachyte, the larger lying towards the north-west. Immediately above the Scaglia, trachyte occurs again (Monte Madonna, Monte Grande, and others). The next formation is light-coloured Tertiary marl, in places resembling tuff; it contains fossil leaves. In this marl lies the trachyte of Schivanoja. Above it comes the principal mass of Nummulitic limestone with fragments of *Conoclypeus conoideus* and large Nummulites. An intercalation of dolerite occurs above this (Teolo, Monte Oliveto, below San Antonio, and other places). Small quantities of dark basic lavas are also present; the dark tuffs which accompany them contain *Orbitoides*, and may be placed approximately on the horizon of Priabona; these dark tuffs extend somewhat far up on the central cone of the Venda and are penetrated by its eruptive veins. With regard to the doleritic tuff I am still doubtful as to whether it may not be a prolongation of the great mass of basic tuff and lava which occurs in the neighbouring district of the Vicentin; above it trachyte again appears (Monte Altorre, Monte Cuin, and others). This trachyte is the last; the isolated summits which it crowns represent portions of streams, which are at present separated from the central cone by erosion; their formation was contemporaneous with that of the largest of the radial dykes (Pendise, Forche, Rua, and others). The trachytic is followed by the rhyolitic phase, ejectamenta of white tuff and flows of rhyolite. At the foot of the Sieve the white tuff contains fossils, and its age, as shown by these, is that of the Bryozoan beds of Val di Lonte, at the base of the Oligocene deposits of the Vicentin. The last member of this long series is formed by the black lavas (Sievite of vom Rath), which lie like a sheet on Monte Sieve and the neighbouring heights, and send dykes with glassy margins into the white tuff.

In this succession of rocks I regard, as I have said above, the lower masses of trachyte as laterally intruded sheets. It was long ago shown that a great volume of oligoclase-trachyte, penetrating laterally between the stratified Jurassic limestones, had torn away a considerable block of them, had carried it along as if floating, and altered it on the lower side. This is the Tithonian fragment of Fontana Fredda, altered by

contact. At the same time it was also pointed out that large masses of trachyte had penetrated laterally like wedges into the spaces between the beds of the Scaglia, and that great fragments of Scaglia had thus formed actual breccias, cemented together by trachyte-like substance[1].

The other trachytic volcanos of Europe either do not possess a foundation formed by such a variety of strata, or else they have not been exposed in the same fortunate manner. To obtain analogous cases of lateral intrusion we must turn to America.

In the last few years a series of remarkable exposures of lavas intercalated with sediments have been described by our fellow workers in North America as indicating a particular type of eruptive mountain: as regards the actual facts there has been a most happy concordance among the observers. General descriptions are furnished by Peale[2], Gilbert[3], Endlich[4], and excellent works on special localities are not wanting. From these it appears that isolated mountain masses exist in which post-Cretaceous volcanic rocks are intruded between sediments, at various horizons, from the Carboniferous to the upper Cretaceous. This intrusion generally occurs in the less resistant shales and marls of the Cretaceous system. The intrusive masses are sometimes small, sometimes they swell to a vast size, taking the form of a plano-convex lens, or of great cake-like masses; it is to these that Gilbert has given the name of '*laccolites*.' As a rule they are associated in groups, side by side, or one above the other; or they may occur singly. The sedimentary strata arch over the laccolite from its edges, and very often considerable portions of the dome so formed are preserved. Occasionally the dome is traversed by a network of radial fissures, now represented by a stellate system of dykes which stand out above the remains of the denuded beds. Most of the exposed laccolites have been revealed by the denudation of a thick covering of lacustrine Tertiary beds which once covered the country far and wide They consist of a rock distinguished by Endlich as 'porphyritic trachyte,' by others termed simply trachyte; only in a few cases are they formed of rhyolite. Laccolites formed of basic lavas have not yet been met with.

The most important examples are: the mountains around Park View mountain, on the continental watershed between North Park and Middle Park; the Spanish Peaks, facing the eastern declivity of the Rocky mountains, and, to the north-west of these, the volcanic mountains of the Huerfano region; then, on the other side of the Rocky mountains, on the

[1] Der Vulcan Venda; Sitzungsber. k. Akad. Wiss. Wien, 1875, LXXI, p. 12.

[2] A. C. Peale, On a peculiar Type of Eruptive Mountains in Colorado; Hayden, Bull. U. S. Geol. and Geogr. Surv. Territ., 1877, III, pp. 551-564.

[3] G. K. Gilbert, Rep. on the Geol. of the Henry Mountains, 4to, 1877 (U. S. Geogr. and Geol. Surv., J. W. Powell).

[4] F. M. Endlich, On the Erupted Rocks of Colorado; Hayden, X. Ann. Rep. of the U. S. Surv. for 1876, 1878, pp. 199-272.

Colorado Plateau, the isolated masses of the Sierras of la Plata, San Miguel, el Late, Carriso, Abajo, la Sal, and, to the west of these, the chain of the Henry mountains which lies a little east of the Waterpocket Flexure (Fig. 13, p. 128) on the western border of the Great Plateau. Many of these mountain masses are very high. The base of the San Miguel mountains is at a level of 2,400 meters; the highest summit, Mount Wilson, which is not, however, a laccolite, rises from this base to a height of 4,352 meters. The summit of the Spanish Peaks rises from the much lower foreland of the Rocky mountains to a height of 4,152 meters.

The intrusion of the eruptive masses into stratified deposits manifests itself under very various forms. Holmes has given a very instructive sketch of the slopes of Mount Hesperus in the Sierra la Plata (south-western Colorado), which shows clearly the intrusion of the edge of a plano-convex laccolite between the Cretaceous shales; in this case, however, the Cretaceous shales, conformably arched over the rounded summit of the laccolite, contain a number of smaller intrusions of trachyte [1]. The same observer has described with great clearness how in the Sierra el Late (to the south-west of the Sierra la Plata) the molten masses which have invaded the Cretaceous shales are crowded with fragments of the latter, but that no fragments of deeper lying sediments are present, a proof that the cleft is sharply defined on the lower side. There is no complete arch visible here, and the lower horizon of the shale is so intimately mingled with the volcanic rock that it may be said to have been absorbed by it.

Still further to the south-west, in the Sierra Carriso, the upper portions of the Cretaceous beds have been completely removed, and the masses of trachyte may be seen intruded into strata ranging from the lower Cretaceous down to the Trias [2].

The Spanish Peaks, far to the east, are particularly characterized by the radial dykes on their surface. They have been described by Endlich. There are two peaks, the imposing height of which we have already mentioned, as well as their position close to the eastern foot of the Rocky mountains, or rather of the Sangue de Cristo chain. The more easterly of the two peaks consists of volcanic rock, the western principally of sedimentary strata, in particular of sandstone and shale of Carboniferous age. These shales have been driven asunder along the joints, great wedges of eruptive material have been forced in, the overlying arch has been broken, and a network of dykes has been formed in it, which extend upwards as far as the Cretaceous beds. Probably these dykes did not all

[1] M. H. Holmes, Geol. Rep. on the San Juan District; IX. Ann. Rep. U.S. Surv. for 1875, 1877, p. 268, pl. xlv, fig. 1.

[2] Holmes, tom. cit., pp. 273, 274.

reach the surface of the ground during the formation of the mountain, but from some of them the lava seems to have escaped to the light of day[1].

The most detailed description we possess is given in Gilbert's Monograph of the Henry mountains. These are five masses situated at almost equal distances from the great Waterpocket Flexure; they rise out of the plateau, itself here 1,500 meters high, and attain in the case of the highest peaks an altitude of 3,429 meters (Mount Ellen) and 3,398 meters (Mount Pennell). The Waterpocket Flexure is dropped on the eastern side to the extent of 7,000 feet (2,134 meters), and the Henry mountains stand on the horizontally stratified sunken area.

The laccolites lie in groups above and beside one another, and form the core of these mountains. Mount Ellen contains about thirty of them, Mount Holmes two, Mount Ellsworth one, Mount Pennell and Mount Hillers a large one each, and several smaller ones. They extend, according to the height at which they occur, from the Carboniferous to the Cretaceous,

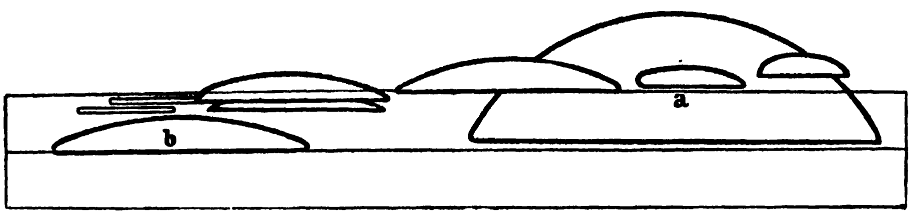



FIG. 18. *The Mount Hillers group of laccolites* (after Gilbert).

a, Hillers' laccolite, and b, Pulpit Lace, surrounded by smaller intrusive masses. The lowest line represents the sea-level, the second line the upper limit of the Carboniferous, the highest line the upper limit of the Jurassic.

but the period of their formation is invariably post-Cretaceous. In Mount Ellsworth and Mount Holmes complete arches of sedimentary strata are present. The Mount Hillers laccolite is the largest, and half of it is exposed; its height is estimated at over 2,000 meters, the diameters of its base measure 6·4 and 5·6 kilometers. From this there is a passage down to the smallest intrusive sills. In every case where the volcanic are in contact with the sedimentary rocks the latter are altered. The laccolites lie here without exception in the less resistant deposits of shale, never in the harder beds of sandstone which separate them. The diagram (Fig. 18) shows the large laccolite of Mount Hillers, with the smaller ones accompanying it; the lowest of these rests on the surface of the Carboniferous, the highest about 300 meters above the base of the Cretaceous formation.

We are accustomed to find volcanic eruptions in connexion with areas of subsidence. This is also the case in the vast region of the Basin Ranges, west of the Colorado Plateau. In this region, which we have not yet had

[1] Endlich, Geol. Rep. on the South-eastern District, tom. cit., p. 127 et seq., pl. xvi.

occasion to discuss, folded strata are thrown down by extensive faults running almost parallel to the meridian.

'Single ranges,' says Clarence King, 'were divided into three or four blocks, of which some sank thousands of feet below the level of others. The greatest rhyolitic eruptions accompanied these loci of subsidence. Where a great mountain block has been detached from its direct connexions and dropped below the surrounding levels, there the rhyolites have overflowed it and built up great accumulations of ejecta. . . . There are a few instances in which hill masses were riven by dykes from which there was a limited outflow over the high summits; but the general law was that the great ejections took place in subsided regions. Quantitatively, these rhyolitic ejections were of enormous volume, building up mountain groups 3,000 to 6,000 feet in thickness, in blocks seventy or eighty miles (113 to 129 kilometers) in length [1].'

The same rule applies also to the great eruptions which accompany the main faults of the Colorado Plateau, and it is not possible to regard the process of eruption by which mighty sheets issue from fissures as of a different nature from that by which laccolites have been intruded in isolated places independently of these main faults. This fact has been rightly recognized by Dutton. The series of events which so long preceded and determined the eruptions of Vesuvius on April 1 and 17, 1871, have confirmed me in the opinion that there is a tendency to over-estimate the force which is ascribed to water vapour in the lava. The outflow of the latter from clefts often many miles long results most likely from the simple laws of hydrostatics, the subsidence of the mountain blocks itself playing an essential part in the welling up of the molten substratum. The question remains whether the pressure, exerted by sinking areas on such masses of lava as do not find an outlet, is capable of producing the intrusions we have just discussed [2].

Let us now return to the Euganaean mountains near Padua.

The difference between the phenomena met with here and those in America lies first in the incomparably smaller dimensions of the intrusive masses in the Euganaeans, next in the absence of yielding strata in the foundation, which is composed entirely of stratified limestone, and finally in the fact that the radial dykes on the summit of the Venda have not proceeded, like those on the mighty Spanish Peaks, from the fragmentation of a sedimentary cupola, but from successive eruptions within an ash cone. But the nature of the processes which led to the lateral intrusion is evidently perfectly similar, and it is therefore quite permissible in the case of the Euganaeans to speak of laccolites in the Tithonian, the

[1] Clarence King, U. S. Geol. Explor. of the 40th Parallel, 1878, I, p. 694.

[2] Dutton, High Plateaus, pp. 129–131.

Biancone, and the Scaglia, even if at the same time they are not very far removed from the old notion of horizontal dykes or sills.

The conception of the elevation of the sedimentary covering as a direct result of volcanic intrusion easily leads to a train of thought which seems to run parallel to the old idea of a certain elevating activity of lavas and the formation of so-called *craters of elevation*.

'One cannot consider the Canaries,' says L. v. Buch, 'otherwise than as a group of islands which have been raised gradually and singly from the sea bottom. The force which is capable of producing so important an effect must be accumulated and augmented for a long time in the interior of the earth before it can overcome the resistance of the masses above it. Then it breaks up the beds of basalt and conglomerate which have been formed at the bottom of the sea, and for a certain thickness deeper down, raises them above the surface of the sea, and makes its escape through the mighty elevation-crater. But a mass so huge as this falls back again on itself and soon closes up the opening, which only served as an outlet for the volcanic force. A volcano is not formed. The Peak rises from the centre of one of these elevation craters as a lofty dome of trachyte; a constant communication of the interior with the atmosphere is now established. . . .[1]'

L. v. Buch thus distinguishes: distension of the ground, collapse accompanied by closing of the orifice, then eruption in the centre of the sunken area. This conception owes its origin to the magnificent crater rings of the Somma; it is only in the first of these three phases that a locally circumscribed, active, elevating force is ascribed to the volcanic mass.

H. Abich, in the admirable description of the Armenian Plateau, with which he has lately enriched our science, has again brought forward this older conception, but only in a restricted sense, i. e. so far as local elevation and subsequent collapse are in question, without any reference to the main features of the configuration of mountain chains and faults, which are regarded as previously existing [2].

Abich illustrates his theory by means of two mountain masses: the Palandocan to the south of Erzerum, and the Dary-dagh near Djoulfa.

The mountains to the south of Erzerum are formed of Cretaceous limestone, gabbro, and serpentine, over which Tertiary volcanic rocks are widely extended. Of these the mighty *Palandocan* (2,947 meters) is also composed, and below its summit on the western side a great crater occurs, the major axis of which measures 9–10 kilometers. In the interior of this vast

[1] L. v. Buch, Physikal. Beschreibung der canarischen Inseln, 1825; Ges. Schriften herausgeg. von Ewald, Roth und Dames, III, 1877, p. 510.

[2] H. Abich, Geol. Forschungen in den Kaukasusländern, II; Geol. des armenischen Hochlandes, I, Westhälfte, 4to, 1882, Atl., pp. 73, 78, 329, et passim.

crater, however, and surrounded by the volcanic masses of its precipitous walls, cliff-like masses of marmorized limestone and alabaster occur in connexion with serpentine, greenish chloritic schist, and rocks of the gabbro family rich in silica; it is of precisely these rocks that the foundation of the mountain is also composed. They form an essential part in the structure of the crater and have been 'overwhelmed by the volcanic masses, which have *apparently* heaved up the foundation of the mountain, have rent it asunder and forced its parts to the north and south[1].'

The second example differs essentially from the first.

In the valley of the Araxes, to the south of Nachitschevan there occurs, above the dislocated Palaeozoic formations, a series which begins with the Nummulitic limestone and has for its youngest member salt-bearing deposits of Miocene age. Red conglomerates, formed almost exclusively of trachyte, are intercalated with this Tertiary series and serve as a means of determining the age of the neighbouring trachyte mountains. Three pillar-shaped mountains of trachyte succeeding each other from the north-north-west to the south-south-east, rise to the east of Nachitschevan above the Tertiary country: these are Nagajir, Asabkew-dagh, and Ingatasch; they stand together on a common elongated ridge of ground. These are followed on the east and south-east by two similar mountains, Ylanly- and Alanja-dagh. Succeeding the first series to the south-south-east, and evidently continuing it, the *Dary-dagh* (1,943 meters) rises to the east of Djoulfa. Its structure is, however, completely different from that of the trachyte pillars, of which it appears to be the continuation. It consists entirely of the strata of the transgressive series, namely, of Nummulitic limestone and trachytic conglomerate; these are bent upwards in a mighty arch, which is traversed by a fault running north and south, with a throw to the west. Volcanic rock does not appear on the line of fault, but argillaceous marl with gypsum and arsenical compounds[2].

Since the strata of trachytic conglomerate also help to form the arch of Dary-dagh, this must be more recent than the whole or at least a part of the trachytic eruptions, and we are thus led to assume that repeated dislocations have taken place along the same line, that is to say, along the older faults on which Nagajir and its companions arose, the trachytic conglomerates and breccias of Dary-dagh being formed at the expense of the latter; then followed the arching upwards of these conglomerates, next the collapse of the arch, and finally the emission of arsenical products.

Palandocan thus exhibits the phenomena of transport, injection, and extensive contact alteration of the sediments; we shall soon meet with them again in the volcanic fissure of the Banat. The case of Dary-dagh

[1] H. Abich, tom. cit., p. 76.

[2] H. Abich, tom. cit., p. 78 et seq.

is different: it reveals repeated movements of the ground before and after the eruptions, but there is no necessity to assume, or at least so it seems to me, that the lava has exerted an active force in the distension of the beds.

After this digression let us now return to the consideration of *intrusions*, and examine first those which are produced by *basic rocks*.

Phenomena of this kind, although not yet described in America, are known in Europe. In coal-mines basaltic intrusions are not rarely met with; they do not as a rule, however, assume the form of huge cakes or lenses, like trachytic laccolites; on the contrary, while of much less thickness they extend over far wider areas, so that they have frequently been taken for contemporary formations, their later intercalation not having been recognized. The relation of basic to trachytic intrusions is thus similar, as far as their form is concerned, to that of the basic and acid lavas flowing above ground, and this circumstance is probably owing to the well-known greater mobility of the basic magma.

It may suffice to mention here a single remarkable example. This is the extensive sheet of basalt, known as the *Whin Sill*, which is intercalated in the lower Carboniferous beds in Northumberland. For a long time it was a matter for doubt whether the Whin Sill was to be regarded as an eruptive flow contemporaneous with the Carboniferous limestone, and spread over it like a mantle, or as a horizontal dyke of unusual dimensions, until a more exact survey of the country by Topley and Lebour established the truth of the latter view.

The Whin Sill has been traced with trifling interruptions for a distance of 120–130 kilometers. It attains a thickness of 23 meters and over, and thins out in a wedge-shaped form to the west. The intercalation occurs as a very extensive sheet between the bedding planes of the Carboniferous limestone and the accompanying beds of sandstone and shale; contact alteration occurs not only below but also above, and smaller veins are also given off in an upward direction. But the Whin Sill does not, as was once supposed, remain in the same stratigraphical horizon; it ascends in the thick beds of the Carboniferous system, and then sinks deeper again, so that the extremes of vertical deviation which it undergoes amount to not less than about 520 meters[1].

[1] W. Topley and G. A. Lebour, On the intrusive character of the Whin Sill of Northumberland; Quart. Journ. Geol. Soc., 1877, XXXIII, pp. 406-421. I should like to mention here that an attempt has lately been made to refer the numerous basalt flows of the Vicentin mountains to a single horizon, and to describe them for the most part as intrusive. I do not share this view. Only in the neighbourhood of Ronca do I know of a small twisted true intrusive vein, occurring in the horizon of the tuff with *Strombus Fortisi*. The difference in age of the basalts is proved beyond all doubt by the variety of fossils in the tuffs. For examples cf. A. Geikie, On the Carbonif. Volcanic Rocks of the Basin of the Firth of Forth; Trans. Roy. Soc., Edinb., 1880, XXIX, p. 476.

The extraordinary extension of the Whin Sill, however, seems to me to suggest the question whether, at so great a distance from the seat of eruption, a force exists capable of elevating strata thousands of feet thick and yet vested in a mass of lava of no considerable bulk. Here too it seems to me more probable that the Whin Sill indicates the course of an oblique fault which followed for long distances the dip of the strata, but with repeated 'jumps' to other horizons, and that this was filled by inflowing basalt. Such 'jumps' may easily arise along the edges of faults as a consequence of dragging. Whether the designation '*intrusion*' can be justly applied in cases of this kind need not at present be discussed; I should prefer the word '*injection*.'—

All these intrusions or injections, in whatever form they occur, proceed laterally from the *pipe*; the latter we will now examine.

There is no volcano known which is eroded to such an extent that its pipe is visible, and at the same time crowned by radial eruptive dykes like those of Monte Venda. There are, it is true, cases where, after the destruction of the ash cone and its dykes, and the exposure of the pipe, the connexion with the surrounding lava flows may still be recognized. These cases may serve us as a point of departure.

In the *Inner Hebrides*, especially in Skye and Mull, great basaltic flows occur; the basalts in the north-east of Ireland are probably a continuation of them. Under these flows the remains of Mesozoic deposits are preserved, which without this protective covering would have been swept away from the Palaeozoic floor. The neighbouring west coast of Scotland consists almost entirely of ancient rocks exposed by denudation.

Judd has shown that four granitic masses rise out of these volcanic outflows on a line running approximately north and south, and that they represent the cores of so many great volcanos. These are: the volcano of the Island of Mull, that of the peninsula Ardnamurchan, those of the Islands of Rum and Skye. The distance between the centres of the most northern and southern of these four eruptive areas amounts to about 88 kilometers; this is the length of that part of a great volcanic line which it is here possible to recognize. The line, however, is probably continued to the north and south. Each of these granitic cores stands in relation to basic rocks of more recent date, especially to those of the gabbro group; the mass of Mull is intersected by these rocks in all directions; in those masses situated further north the basic core is juxtaposed to the granite, into which it sends off veins. In the neighbourhood of these points of eruption the sedimentary rocks are very much altered and the basaltic dykes crowded together. A period of rest and denudation seems to have followed the formation of the granitic masses before the basic eruptions occurred. These took place on dry land; buried forests and deposits with Miocene plants occurring at their base bear witness to

the fact. The largest ash cones, those of Mull and Skye, must have reached a height of over 4,000 meters[1].

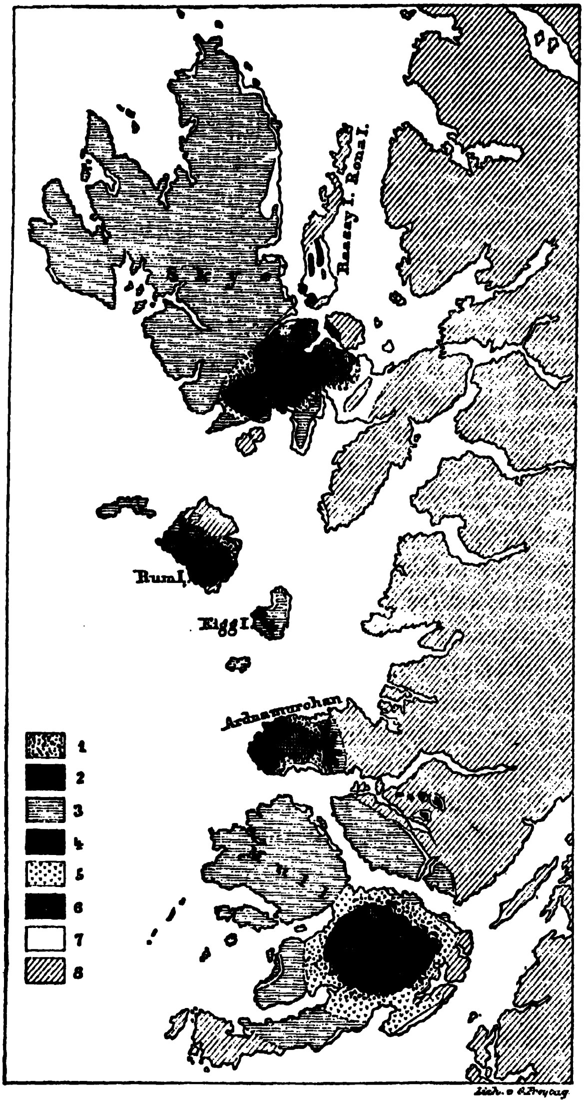



FIG. 19. *The volcanos of the Inner Hebrides* (after Judd).

1, Volcanic tuffs and agglomerates; 2, Most recent eruptive rocks; 3, Basic lavas; 4, Basic intrusive rocks; 5, Acid lavas; 6, Acid intrusive rocks (chiefly the eastern centre of eruption on Ardnamurchan); 7, Mesozoic and Carboniferous beds; 8, Ancient rocks.

From these granitic masses actual laccolites are sent off into the Mesozoic beds.

As early as 1871, before Judd had pointed out the significance of the granite cores, Geikie had here recognized 'amorphous' intrusive masses consisting of syenite, felsite, or quartz porphyry which, penetrating irregular fissures, are bounded by no parallel limiting surfaces. Such masses are mentioned as occurring on the island of Raasay, to the north of the volcano of Skye, on Skye itself, and on Eigg, and between the volcanos of Rum and of Ardnamurchan. On Eigg in particular three such felsite masses are described, rising above the surrounding basalts. The largest, 50–70 meters high, forms the northern end of the island and 'appears to have risen approximately along the bedding of the oolitic strata, and thus to form of itself a large rude bed[2].'

Judd has confirmed the intercalation of these

[1] J. W. Judd, The secondary Rocks of Scotland, 2nd paper, On the ancient Volcanos of the Hebrides and the Relations of their Products to the Mesoz. Strata; Quart. Journ. Geol. Soc., 1874, XXX, pp. 220–300, pl. xxii, xxiii, and map in 1878, XXXIV, pl. xxxi.

[2] A. Geikie, On the Tertiary Volcanic Rocks of the British Islands, 1st paper; Quart.

masses in the Mesozoic series and showed, as early as the year 1874, that the acid rocks here form thick, lens-shaped intrusive masses, which are confined to areas at a moderate distance from the eruptive centre, while the basaltic lavas may follow the bedding planes for great distances.

The acid rocks consist of different varieties of felsite, more or less quartz-bearing, frequently of porphyritic structure, passing with the development of hornblende into syenitic granite. The basic intrusions are almost always doleritic, containing much olivine, and with transitions on the one hand to fine-grained gabbro, on the other to basalt.

We have seen that the basic lavas of these volcanos rest on Tertiary plant-bearing deposits; in the same way deposits containing brown coal may be seen in the Faröe Islands intercalated between basaltic lavas, and it is generally known that similar facts are met with in Iceland. These formations bear witness to an extensive continent which in the latter half of the Tertiary period stretched from Scotland far away to the north [1].

Near *Predazzo* in South Tyrol the pipe of a volcano of Trias age is exposed to view by the valley of the Avisio running north and south, and the Val Travignolo, which opens into the former on the east. It is a wonderful spot. Since Marzari-Pencati furnished the first description of it, in 1823, it has been the theatre of constantly renewed investigations, and the manifold phenomena it presents are still far from sufficiently explained [2].

Here we can only mention a few of the main features of its structure. In the following discussion the chief interest lies in the circumstance that we should be able definitely to determine the age of an eruptive centre of granite and syenite situated in the midst of the Alps.

The Avisio meets the Val Travignolo quite close to the little town of Predazzo. The main ridge to the west of the Avisio is formed by the Dosso Capella, with the slopes of Ai Canzocoli turned towards Predazzo; to the south of the Val Travignolo rises the Malgola, to the north of it the Mulatto. Fig. 20 was drawn from the eastern side in Val Travignolo; on the left stands the Malgola, on the right the Mulatto, with Ai Canzocoli and the Dosso Capella in the centre. Only three chief types of eruptive rocks are distinguished in this little sketch, namely, granite,

Journ. Geol. Soc., 1871, XXVII, p. 294. These masses could not be represented on the little map, fig. 19, on account of its small scale.

[1] J. Geikie, On the Geology of the Faröe Islands; Trans. Roy. Soc., Edinb., 1880–1881, XXX, p. 240.

[2] From the abundant literature on this subject I will only mention F. v. Richthofen, Geogn. Beschreib. der Umgebung von Predazzo, S. Cassian u. s. w., 4to, 1860; C. Doelter, Ueber die Eruptivgebilde von Fleims, nebst einigen Bemerkungen über den Bau älterer Vulcane, Sitzungsber. k. Akad. Wiss. Wien, 1876, Bd. 74, pp. 857–878, map of the neighbourhood of Predazzo; E. v. Mojsisovics, Die Dolomitriffe von Südtirol und Venetien, 8vo, 1879, pp. 344–393; E. Reyer, Predazzo, Jahrb. geol. Reichsanst., 1881, XXXI, pp. 1–56 and map.

syenite (Monzonite), and melaphyre. This is not the place to describe the numerous dykes and the secondary modifications of the rocks. The left side of the Mulatto is formed up to the summit of lower Trias deposits; its slope facing Predazzo consists of eruptive syenite; the line of contact and of the marmorization of the Trias limestone, that is, the outer limit of the eruptive mass, crosses the mountain obliquely. The syenite on this declivity includes one larger and several smaller masses of marmorized Trias limestone, and numerous steeply ascending dykes of flesh-coloured orthoclase porphyry, which look as though they proceeded from the granite mass which we shall meet directly on the other side of the valley.

The boundary of the eruptive mass may be seen, just as sharply defined, on the Dosso Capella, which appears in the middle of the sketch

FIG. 20. *Predazzo* (South Tyrol).

View from the Boscampo bridge (Val Travignolo), near the middle of the ancient centre of eruption. On the left: *Malgola*, syenite and Trias limestone (left white); on the right: *Mulatto*, syenite, granite (closely dotted), and dark augite rocks; in the middle: *Dosso Capella*, contact of Trias limestone and syenite on the Canzocoli; above the syenite melaphyre; in the background: melaphyre overlying Trias limestone.

in the background behind Predazzo. It ascends the mountain obliquely. In the lower portion of the slope eruptive syenite occurs in contact with the limestone, and the place called Ai Canzocoli is the locality long famous for the silicates of the zone of contact; further up the limestone comes into contact with melaphyre. Behind Dosso Capella, on the hills to the right, melaphyre may be seen resting on limestone; this is a portion of the lava streams which issued from the volcano. At the bottom of the valley of the Avisio a projecting granite mass appears beneath the syenite; in the sketch it is concealed by the foot of the Mulatto.

To the right, on the summit of the Mulatto, are augitic rocks which form striking dark walls of no great height. They are continued from

the projecting ridge of the Mulatto to the bottom of the valley near Predazzo, as a long dyke which intersects all the deeper rocks. The latter consist of tourmaline-bearing granite and syenite; they are continued on the other side of the mountain towards the foot of the Dosso Capella and the Sforzella. The whole Mulatto is of volcanic origin; its junction with the Trias limestone lies close to the right, outside the sketch, in a ravine descending from Monte Viezzena.

The distribution of the rocks, the silicates at the points of contact, the numerous dykes, and the intercalation of melaphyre lavas and tuffs in the Trias beds leave no doubt as to the volcanic origin, the genetic connexion, and the age of these remarkable features. They are repeated immediately to the north-east, as on Monte Monzoni, with a magnificent development of lateral dykes, though no granite is there visible. Laccolites are not known to exist in this region.

As the example of the mass of the Finster-Aarhorn has shown, the conversion of stratified fossiliferous limestones into white marble, at their junction with granite masses, may be effected by pressure alone; consequently, it is the presence of the crystallized silicates in the zone of contact which furnishes the most conclusive testimony to the eruptive and volcanic nature of the syenite mass of Predazzo. The same characteristic, however, recurs in a portion of the margin of the mighty mass of Adamello.

The mass of the Adamello rises between Val Camonica and the valley of the Judicaria on the borders of Lombardy and the south-western Tyrol. Its longest side strikes to the north-north-east, and follows closely the great fracture-line of the Judicaria which lies to the east. The most remarkable rock of this mountain mass may be easily recognized by its numerous short thick columns of dark hornblende and black mica flakes set in a white ground-mass; G. v. Rath has named it tonalite, Zirkel regards it as most nearly related to quartz-diorite [1].

Where the tonalite mass of the Adamello meets the Trias limestone to the south-east, the contact phenomena of Predazzo reappear. The sketches which Lepsius has published of the Val Bona and the Val Bondol leave no doubt as to the correspondence between the phenomena in these two regions. For instance, on the southern declivity of the Cima Bruffione in the Val Bondol we see the tonalite meet the nodular Trias limestone in an almost vertical junction; the Trias, which dips steeply towards the tonalite, is converted into marble and impregnated with contact silicates [2].

In discussing the southern Alps we shall again touch upon this remarkable circumstance.

In the volcanos of the Hebrides both the position of the pipes and the

[1] G. v. Rath, Beitr. zur Kenntniss der erupt. Gesteine der Alpen, Zeitschr. deutsch. geol. Ges., 1864, p. 249; Zirkel, Lehrb. der Petrog., 1866, II, p. 22.

[2] R. Lepsius, Das westliche Südtirol, 4to, 1878, pp. 208, 222.

remains of the ejected lavas may still be recognized; their activity extended into the Miocene, or even to a later period. In the volcanos of Predazzo and Monzoni the pipes may also be recognized, and although they are of incomparably greater age than those of the Hebrides, the lavas and tuffs pertaining to them may still be seen intercalated with the Trias limestones.

The eruptive centre of *Rézbanya* in the south-east of Hungary, which is described by Peters and Posepny, is in a similar stage of denudation; here for the first time we meet with metalliferous deposits in immediate connexion with an eruptive mass, within the aureole of volcanic contact. Rocks which Peters terms syenite and syenite-porphyry alter the surrounding beds and produce in the Neocomian limestone a mixture of wollastonite, garnet, and blue calcite.

The long thin veins of volcanic rock, which penetrate into the fissures of the surrounding country and enclose pointed wedges of it, Posepny regards as a fresh proof that these eruptive masses are not *impelling* but *impelled*. He considers the subsidence of a neighbouring area as the cause of these eruptions; the eruptive magma is forced into the veins by the pressure of the sinking mass[1].

To the south of the river Temes, which flows down from Transylvania, a mountain chain runs through the *Banat* down to the Danube, of which the loftiest point, Muntje Semenik, is 1,450 meters high, while its mean height is about 800 meters. The strike of its strata is from the north-east or north-north-east to the south-south-west, and in this direction the chain is continued across the Danube to Servia. The great river in its winding course crosses both this chain and those parallel to it on the east, and thus gives rise, between Moldowa and the Iron Gates, to a series of great rapids. We are only concerned here with the western portion of the chain, and more particularly with its eastern slope.

This chain consists of long folds of mica-schist with some gneiss, then Coal-measures, red Permian sandstone, Jurassic and Cretaceous limestone. A very important fault, running north and south, traverses the mountains; it meets the folds which strike to the south-west and south-south-west at an acute angle, and cuts off the Mesozoic strata on the west so that on the other side, west of the fault, only low hills of mica-schist or the open plain are to be seen. That part of the fault which lies on the northern side of the Danube in the mountains of the Banat, that is, from Deutsch-Bokschan in the north to Moldowa on the Danube in the south, is occupied for a distance of 78 kilometers by a series of ancient centres

[1] C. Peters, Geol. u. mineral. Studien aus dem südöstlichen Ungarn, Sitzungsber. k. Akad. Wiss. Wien, 1861, XLIII, pp. 385–463, and XLIV, pp. 81–187, map and plate; F. Posepny, Geol.-montan. Studie der Erzlagerstätten von Rézbánya, from Földtani Közl., IV, 1874, 8vo, Budapest, 198 pp., map and plate, in particular p. 190.

of eruption, as is shown in Fig. 21. But the fault crosses the Danube and is accompanied further to the south by similar centres of eruption.

The chief source of information on this folded region is a work by Johann Kudernatsch, published in 1857, describing its most important parts. Many views on the structure and formation of mountains find expression here which were not generally accepted until a much later period. For the western portion of the fault represented in Fig. 21 I must refer in particular to the special geological maps published by the State Railway Company of Austria in 1860, on which the map published by Cotta in 1865 is also based [1].

The most important outcrops of volcanic rock in this area are, proceeding from south to north, those of Moldowa, Kohldorf and Szászka, Cziklowa and Oravicza, Dognácska, and finally the great irregular mass north of Bokschan. With the exception of the last, each of these takes an extremely elongated form in the direction of the fault, so that, on the length of 78 kilometers here represented, the volcanic rock is actually visible for a distance of about 47 kilometers, and there is no reason to doubt that further denudation of the surface would reveal, instead of these isolated patches, a single connected zone of volcanic rock.

These eruptive rocks were originally described as syenite or granite; Cotta gave them a new name, Banatite; they are, as later investigations of Niedzwiezki [2], Szabó [3], and others have shown, of diverse composition, and should be described as syenite proper, or quartz-bearing diorite, diorite, andesite, and andesine-quartz-trachyte. G. v. Rath, in agreement with Niedzwiezki, calls the most common type among them quartz-diorite, and compares it, as Cotta does also, with the metalliferous propylite, which occurs in so many places in Hungary and Pennsylvania, and with the tonalite of the Adamello [4]. Near Moldowa an imposing dyke of basalt also occurs.

Wherever the syenitic or dioritic rock comes in contact with the Mesozoic limestone, the latter is altered; garnet, wollastonite, idocrase, mica, blue calcite, and a whole series of minerals characteristic of volcanic contact are produced. The numerous metalliferous deposits of this chain also lie within the zone of contact; they contain magnetic iron ore, lead

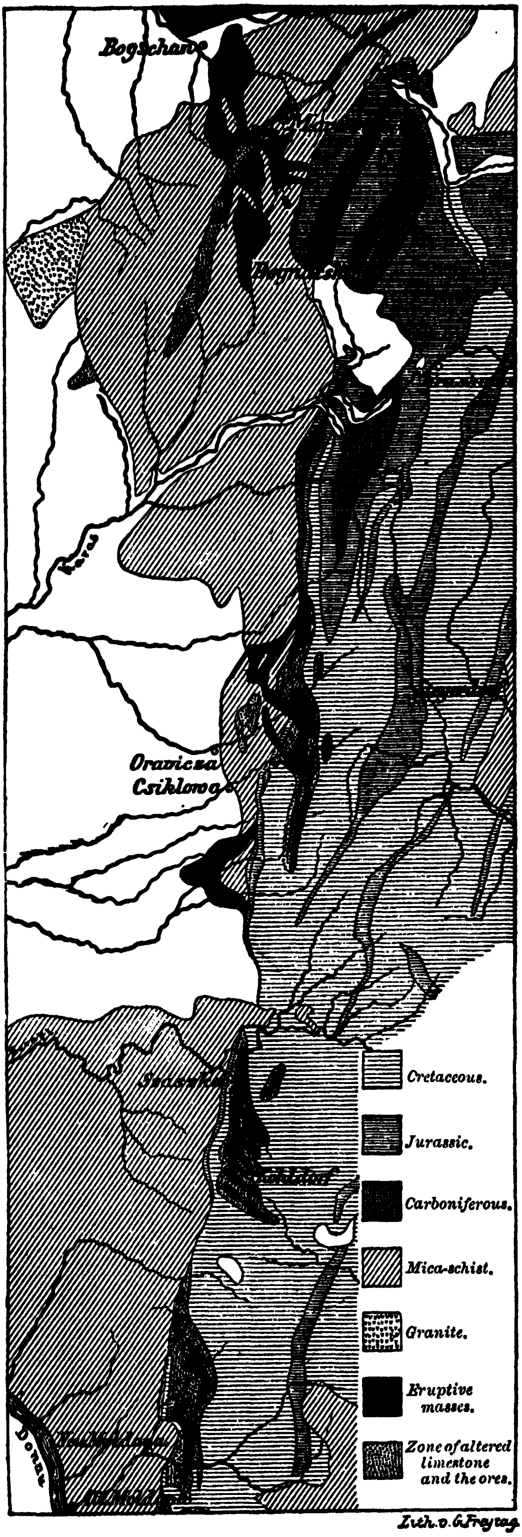
[1] J. Kudernatsch, Geol. des Banater Gebirgszuges, Sitzungsber. k. Akad. Wiss. Wien, XXIII, 1857, pp. 39–148, map and plate; B. v. Cotta, Erzlagerstätten im Banat und in Serbien, 8vo, 1865, 108 pp. and pl. L. Loczi does not accept the northern prolongation of the fissure assumed by Cotta (A Hegyes Drocsa-hegység Asvany-Lelhelyei, 8vo, Budapest, 1877, p. 10).

[2] J. Niedzwiezki, Zur Kenntniss der Banater Eruptivgesteine, Jahrb. geol. Reichsanst., 1873, XXIII; Tschermak, Miner. Mitth., pp. 255–262.

[3] Szabó, in Földt. Közl., VI, 1876, pp. 112–132, et passim; also F. v. Hauer, Die Geologie und ihre Anwendung, &c., 2. Aufl., 8vo, 1878, 540 pp.

[4] This remarkable locality was described in detail by G. Marka, Einige Notizen über das Banater Gebirge; Jahrb. geol. Reichsanst., 1869, XIX, p. 318 et seq., pl. viii, ix.

FIG. 21. *The volcanic line of the Banat* (from the Surveys of the Imp. Royal State Railway Company of Austria).



and copper ores, silver and gold. The individual eruptive centres are surrounded wholly or in part, according to their position with regard to the limestone, by an aureole of metamorphism. The eruptive area of Morawica lies in mica-schist, but crosses a band of limestone which it alters and impregnates with ores [1].

Cotta has expressed the opinion that no actual eruptions at the surface occurred along the Banat cleft, but the almost complete absence of lateral lava flows cannot be regarded as a sufficient proof of this. The degradation of the country necessary for the exposure of the fissure in its present form must have been so considerable that ejected lavas would have succumbed to it over a large area.

Notwithstanding this enormous amount of denudation, we cannot assign a higher age to the quartz-diorite of the fissure than that of the Tertiary period, since the Cretaceous limestones have been altered along the contact. It is possibly contemporaneous with the propylite of the Carpathians, where the eruptions must be placed in the Oligocene, or in the first half of the Miocene period [2].

The denudation which has taken place since about the middle of the Tertiary period appears then to have been sufficient to lay bare the contents of the fissure for over more than a half of its course of 78 kilometers. If the demolition were further advanced we should see a single zone of quartz-diorite. But this demolition might easily proceed so far that the neighbouring Mesozoic limestones, and with them the contact formations and ore deposits, would disappear, and instead of the present diversified structure of the mountains nothing would remain but a belt of diorite or syenite, imbedded in mica-schist and gneiss, to which many an observer would straightway assign an Archaean age.

Having thus considered the ash cones of the present day and presented in their natural order the pictures afforded by denudation, we come gradually to the manifold products of abyssal processes, such as may be seen in the ancient eroded mountain masses of Bohemia or Norway, as well as here

[1] G. v. Rath, Sitzungsber. Niederrhein. Ges. für Natur- und Heilkunde zu Bonn, 13. Januar 1879.

[2] In the same region, but further to the east, there is a second similar, but less generally known line of eruptive centres. This runs northwards from the town of Maidanpek, in Servia, crosses the Danube, and in the Ljubkowa valley, immediately to the north of the river, contains ores in the corresponding contact formations (Zepharovich, Berg- und Hüttenm.-Zeitschrift, V, p. 12; also J. Böckh, Geol. Notiz. über d. südl. Theil des Comit. Szörény, from Földt. Közl., 1879, p. 29, note for similar eruptive centres; also op. cit., 1880, and in particular Hugo Szterényi, op. cit., 1883, p. 142). Kudernatsch even believed that he had observed contact phenomena in the limestone on the western border of the great granite ridge of Puschkasch which lies to the east of Steyerdorf (Jahrb. geol. Reichsanst., 1855, VI, p. 228), but the statement, according to Tietze's observations, requires further investigation (op. cit., 1872, XXII, p. 43).

and there in the younger folded chains. It was in this way that the remarkable syenitic, and in its southern portion granitic, ridge was formed, which, near Brünn, follows the eastern border of the Bohemian mass and separates it from the Sudetes. The diagram on page 186 (Fig. 24) indicates its position in rough outline, and shows how it separates two great masses of the earth's crust wholly different in structure [1].

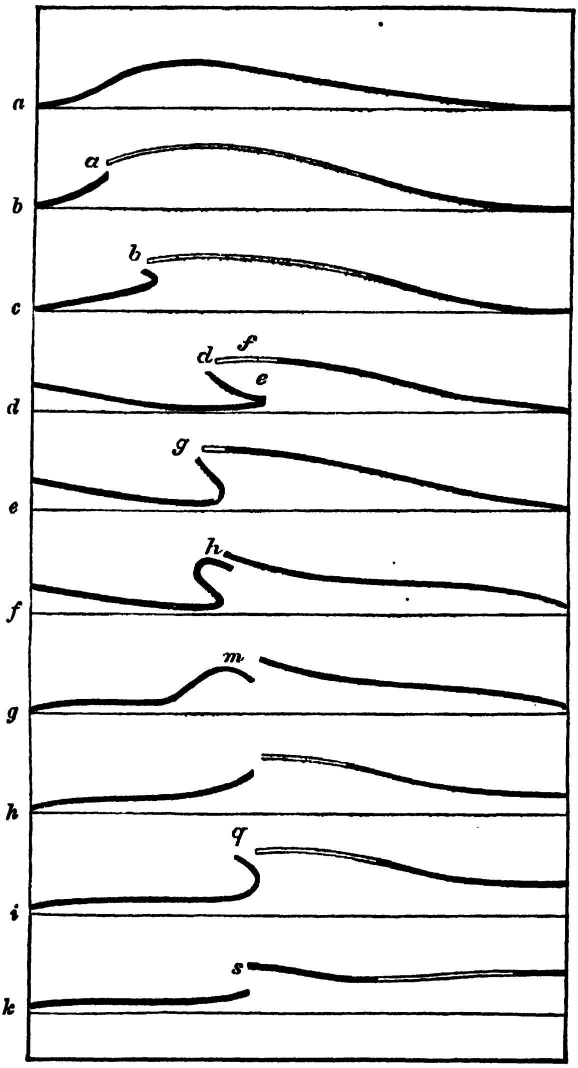



Fig. 22. *Sections to correspond to Fig. 23.*

Denuded volcanic ranges of this description we shall here term *cicatrices.*

Denudation exposes to view, however, not only cicatrices but old sheets of lava, abyssal dykes and injections of many kinds, perhaps also intrusive masses or true laccolites formed at a great depth. It was from a consideration of such facts that Judd, after examining the eruptive centres of the Hebrides, was led to designate extensive masses of granite, such as that of the province of Leinster, as exposed *reservoirs.*

Before turning to the difficult question of the origin of such granite masses some further examples may be quoted.

In America the term laccolite includes, besides the already mentioned lenticular masses of trachyte, the massive rocks of the *Elk mountains* in Colorado. This chain, situated in the Rocky mountains, strikes from the western side of the great

[1] The closer relations of this ridge to the neighbouring mountains have already been discussed, Entstehung der Alpen, pp. 67–71.

Sawatch chain to the north-east; several peaks exceed a height of 4,200 meters. Its structure has been described by Holmes[1].

From the north-west to the south-east three larger granite masses arise, Sopris Peak, Snow Mass Group, and White Rock Group, which runs out in a small spur to the south-west. Endlich describes the granite of these mountains as a mixture of orthoclase, oligoclase, quartz, and muscovite, with a little biotite; it is generally white or grey in colour; porphyry and diorite sometimes accompany it[2]. The sedimentary series which surrounds the granite masses begins with unfossiliferous quartzite, some hundreds of feet thick, followed by Carboniferous limestone and a further series of great thickness, which extends upwards as far as the upper part of the Cretaceous system. The Cretaceous series contains intrusive masses of rhyolite and trachyte.

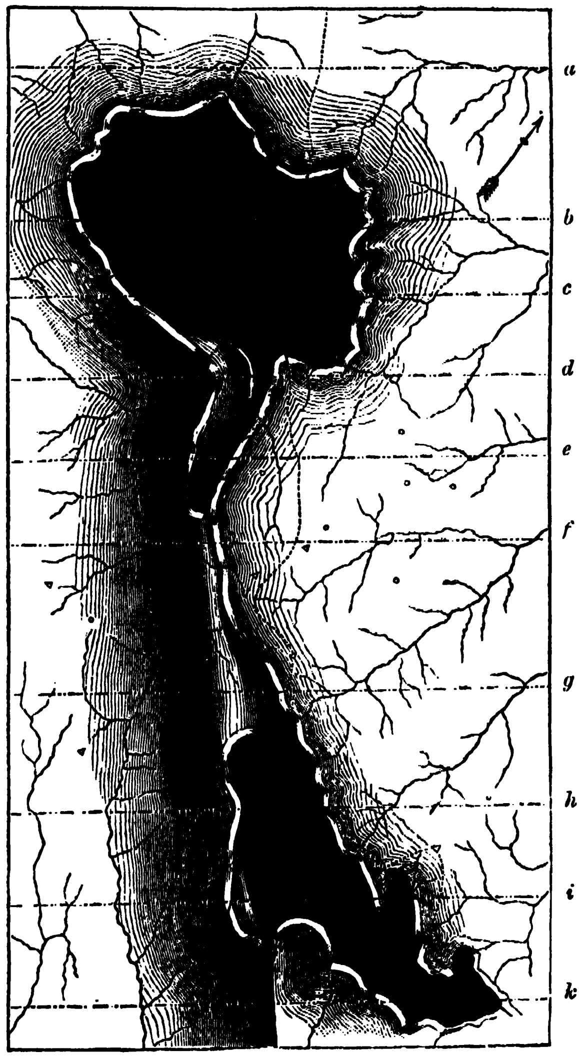



FIG. 28. *Arrangement of the lowest parts of the Cretaceous formation around Snow Mass and White Rock in the Elk mountains* (after Holmes).

As regards their tectonic relations, we see that the two largest granite masses, Snow Mass Group and White Rock Group, stand on a common line of disturbance, which is termed a fault-fold, and is accompanied by a distinct lateral movement of the mass directed from the north-east to the south-west at right angles to the

[1] W. H. Holmes, Report on the Geology of the N.W. Portion of the Elk Range; Hayden, 8th Ann. Rep. U. S. Survey for 1874, 8vo, 1876, p. 58 et seq.

[2] Endlich, On the Erupted Rocks of Colorado; Hayden, Ann. Rep. for 1876, 8vo, 1878, pp. 210-211.

strike. This later movement was so considerable that on the south-west border the granite is thrust over the sediments, while in the interval between the two masses the sedimentary beds are folded in.

The extent of the lateral movement and the occurrence of trachytic masses in the outer Cretaceous zone appear to explain why these two great granite masses, which are certainly connected at some distance below the surface, have been regarded as true laccolites of post-Cretaceous age, while some investigators have even been inclined to bring the intrusion of the granite into causal connexion with the formation of the chain itself.

Holmes expresses himself with great caution on this point; it would not be hard to imagine, he says, that while the lateral displacement and folding were in process, the plastic mass beneath followed the movement, and so gave rise to the existing structure, and at the same time intruded itself, or was intruded, through the line of fault as the two great masses of the Snow Mass and White Rock Groups[1].

This point of view recognizes the folding force as the prime agent in producing the structure of the country, but other authors consider the Elk mountains to have been raised and folded by the intrusion of post-Cretaceous granite. The granite, however, appears to lie always in the same stratigraphical horizon, in this respect, as in others, perfectly resembling the passively overfolded masses of the Cima d' Asta or the Jungfrau.

The opinion expressed by Holmes accords more or less with the views propounded by Lossen on the granite of the Harz mountains. Lossen thinks 'that the unilateral (heteroclinal) fold might, with increasing pressure, be rent across along the strike; its upper limb would then be driven upwards, and with a continued increase in pressure a fissure might be produced up which the eruptive rock would be forced.' In his latest work Lossen calls the Harz 'a twisted elliptical orographic mass, forming a mountain-knot, with eruptive magma squeezed out at the dynamic foci.' From certain passages we even perceive that Lossen pictures the granite as a plastic mass subjected to the influence of the lateral movement, and of the step-like arrangement of the folds he says: 'The steps are the solidified waves of the granitic magma, which have shared in the fold-producing movements of the solid crust[2].'

This granite has produced contact alteration in the grauwacke of Tann, which in some places still covers it; the granite has therefore, like the American laccolites, exercised a metamorphic influence from below upwards.

We may again emphasize the point that the older theory of the elevation of mountains by means of granite finds, according to Holmes, no confirmation in the Elk mountains, nor according to Lossen in the Harz, but that both observers consider the folding of the mountains as the first

[1] Holmes, op. cit. p. 68.

[2] Lossen, Geologische und petrographische Beiträge, pp. 4, 21, 43.

and decisive event, and the extrusion of granitic magma merely as an accompanying phenomenon determined by the folding.

A number of granite masses are known, which have the following characters in common:—

(*a*) They lie imbedded in older stratified rocks, most frequently in schist, they are revealed by denudation, and their form, as far as it can be recognized, is that of *large, irregular loaves or cakes.*

(*b*) They have produced contact metamorphism, not only in a lateral direction, but also from below upwards, and are therefore *younger than the overlying strata.*

(*c*) In many cases they send off *apophyses* laterally or from below upwards; these apophyses are injected into fissures, the formation of which must have *immediately* preceded the injection.

The Drammen granite in the neighbourhood of Christiania is, according to Kjerulf, covered for considerable distances by various horizontally-lying members of the Silurian system, all of which it alters along the plane of contact, enclosing fragments of them and injecting them with dykes [1].

The two granite masses of Barr-Andlau and of Hohwald in the Vosges, which have produced the alteration in the Steiger schists so admirably investigated by Rosenbusch, are enclosed in these schists and send off apophyses into them [2].

The great granite masses of the Erzgebirge present similar relations, and are still partly overarched by the mass of schist into which they have been intruded and which they have altered. These masses, it must be admitted, stand in no perceptible connexion with the strike of the Erzgebirge; the great Neudeck mass extends in a direction more or less at right angles to the chain and is cut off in the south by a great terminal fracture, in precisely the same way as the masses of the Vosges are traversed by the faults which play so important a part in the shaping of that chain.

It cannot be denied that the most important characteristics of these granite masses, and in particular the contact metamorphosis produced in the overlying strata, reappear in the trachytic laccolites of North America. They are, however, of much more imposing dimensions, and the question arises how such extraordinarily large cake-shaped masses, with a major axis measuring 10 or 20 kilometers or even more, can have been subsequently intercalated at a definite horizon, as, for example, in a particular

[1] T. Kjerulf, Die Geologie des südlichen und mittleren Norwegen (German translation by A. Gurlt), 8vo, 1880, in particular pp. 73 and 242, fig. 195; E. Reyer, Vier Ausflüge in die Eruptivmassen bei Christiania, Jahrb. geol. Reichsanst., 1880, XXX, pp. 27-42.

[2] H. Rosenbusch, Die Steiger Schiefer und ihre Contactzone an den Granititen von Barr-Andlau und Hohwald; Abhandl. zur geol. Specialkarte von Elsass-Lothringen, Bd. I, Heft II, 1877.

zone of schist, or even, as near Christiania, in a group of stratified rocks lying fairly close together.

It is absolutely necessary that the injection of a granitic mass, possessing so high a temperature as to be capable of altering the surrounding rocks, *should be preceded by the formation of a corresponding cavity.*

The tangential or folding movement of the outer portions of the planet has been sometimes called a 'movement of the crust,' but the conception of the 'earth's crust' involves many obscurities. Processes such as have occurred along the Belgian 'faille du Midi' show that it is possible for some parts to be lifted off and thrust over others. This lifting-off is probably not uncommon below ground, especially with an unequal tangential pressure or unequal resistance. It is likely to occur most frequently in the deep-lying zones of schist, which would lend themselves most readily to it; and in this way very large, more or less lenticular spaces might be formed, which the granitic mass would enter, altering the overlying strata, and sending off dykes into the fissures. There is often nothing to indicate that the whole mass of younger sedimentary rocks which overlie the lifted-off or pushed-off surface has been broken through, or that a volcanic eruption, producing the comminuted materials which accompany an explosion, occurred at the surface of the ground. The magma simply filled the space as far as it extended, and consolidated in it, forming a cake of rock or true *batholite,* which would never be capable of giving rise to any further mountain building, but might in certain cases, in consequence of its great bulk, its rigidity, and configuration, passively influence this process as regards certain subordinate features.

The granite masses of the Pyrenees are, as Zirkel has clearly shown, of widely different ages. The same is true of the granite cores of the Alps. Several of these lie, probably as true batholites, in beds of Carboniferous age, others occur at much deeper horizons, some again are far younger; we have already described how those near Predazzo are associated with true volcanic phenomena.

High above the Bernina Hospice there are superposed upon the granite masses of white limestone, half converted into marble, either by pressure or volcanic contact, which contain numerous fossils, apparently of Rhaetic age. Far below, in the Val Trompia, the workings of the Arnaldo mine have revealed a mass of green granite, the bossy surface of which is at one spot intimately united with the superposed (apparently Carboniferous) micaceous slate, while at another place close by it is immediately covered by red Permian sandstone.

The Alpine mountains, however, which afford us such clear insight into these phenomena, also reveal other and quite unexpected occurrences. While syenitic and dioritic rocks are met with in the pipes of Tertiary volcanos, Stache and John make us familiar with other volcanic rocks, which bear

no small resemblance to recent andesites and propylites, and which near the sources of the Adige and the Adda are intercalated at the base of the whole thickness of the Mesozoic series [1].—

Let us now return to the formation of large cavities in the interior of the earth. The detachment of a considerable mass of strata may be sufficient to explain the intrusion of the now consolidated lenticular granite masses which alter the overlying strata. But independently of this fact, and for quite other reasons, a theory was propounded many years ago that in the interior of the earth no connected pyrosphere exists, but that the lavas rest in large isolated cavities, in subterranean lakes, so to speak. Hopkins considered these lava-lakes as the remains of the original molten mass of the planet and designated them 'residual lakes.' A fact, very remarkable in spite of all exceptions, has recalled attention to this older theory. I refer to the strikingly constant repetition of eruptive rocks in the same chronological order, known as Richthofen's series, which occurs in regions so remote from one another as Hungary and West America for example. The order of this remarkable series, which Richthofen's keen glance first perceived, is propylite, andesite, trachyte, rhyolite, basalt. Its constancy has often been denied, but its recurrence in the vast regions of western America has now been placed beyond doubt, while according to Godfrey it is likewise the rule in Japan [2]. The confirmation of the existence of the series in the great faulted areas of the high plateaux of Utah has led Dutton to theoretical discussions, in which the local and limited nature of the subterranean lava-reservoirs is emphasized, but Hopkins's conception of them as residues surviving from a once general condition of molten fluidity is denied. According to Dutton such reservoirs, which he names *maculae*, are supposed to be formed afresh in the interior of the earth, and he connects this supposition with the theory of liquefaction through decrease of pressure, lately put forward by Clarence King [3].—

In the preceding chapter we stated that the dislocations of the earth manifest a tendency to resolve themselves into radial and tangential stresses, but that direct results of the radial tension, an active attraction as it were towards the centre of the globe, would be difficult to prove: on the other hand a passive descent of large portions of the earth's crust is of

[1] J. Stache and C. v. John, Geol. und petrogr. Beitr. zur Kenntniss der älteren Eruptiv- und Massengesteine der Mittel- und Ostalpen; Jahrb. geol. Reichsanst., 1877, XXVII, pp. 143–242, and 1879, XXIX, pp. 317–404, plate. Teller and John have recently added to our knowledge of the remarkable eruptive district of Klause, which is formed principally of diorite. It lies between the granite mass of Brixen and the great Permian porphyry sheet of Bozen. Op. cit., XXXII, 1882, pp. 589–684, and plate.

[2] F. Baron Richthofen, The natural system of Volcanic Rocks, Mem. California Acad. Sc., 1868, I, pp. 39–133, in particular p. 67; J. G. H. Godfrey, Notes on the Geology of Japan, Quart. Journ. Geol. Soc., 1878, XXXIV, p. 542.

[3] Dutton, High Plateaus, pp. 116, 128, *et passim*.

frequent occurrence. This passive subsidence also presupposes large cavities. It is in such regions that the extrusion of lavas is most frequent. The conception which results from a comparison of these observations is approximately the following:—

The upper peripheral portions of the globe are held fast like an arch by tangential pressure. Either radial tension or tangential thrust serves to separate a portion of the globe from the interior, and a large cavity, a macula, more or less parallel to the surface of the earth, is formed, which in the case of radial rupture is of great lateral extension, in the case of thrust more lenticular in form; this fills with lava. If at the surface the tangential pressure finds expression in folding, or overthrusting, then the arch sinks into the macula behind the fold or overthrust, and lava wells forth along the fissures or faults.

How far this conception is supported by facts is a question that will be discussed in a later chapter.

In conclusion, another phenomenon may be mentioned which appears to be common to many centres of eruption. This is the limited local subsidence, or, to use Reyer's expression, the invagination of the volcano and the surrounding country. I do not refer to the often quoted examples from the immediate neighbourhood of recent volcanos, for example of Signal Post Hill on Santiago (Cape Verd Islands) or of the smaller eruptive centre near Auckland (New Zealand), because in these cases the occurrences are only of small extent[1]. I speak of the whole mass of the volcano. We have the concordant testimony of Judd in the case of the volcano of Mull, Mojsisovics in that of the eruptive area of Predazzo, and Reyer in that of the mass of the Venda, that subsidence has taken place[2].

'One receives an impression,' says Mojsisovics, 'as though on the periphery of the eruptive area the fractured mountain had been plunged into cavities formed beneath.' We have already had occasion to remark on the tendency to underestimate the volume of the material ejected during a great eruption, and on the comparatively small size of the resulting cone as compared with the mass of finely divided material, which in such catastrophes darkens the sun over wide areas.

In order to obtain a comprehensive view of the denudation series in its main features we will return to the most recent volcanos of Central America.

The series begins with the modern volcano near Leon, with the eruptive centre in the Lake of Ilopango, and Izalco; not one of these is a century old; in addition we may mention Jorullo and Monte Nuovo.

[1] Scrope, Volcanos, p. 273; Darwin, Geol. Observ., 2nd ed., p. 12; Heaphy, Quart. Journ. Geol. Soc., 1860, XVI, p. 245.

[2] Judd, Quart. Journ. Geol. Soc., 1874, p. 256; Mojsisovics, Dolomitriffe, pp. 377, 378; Reyer, Eugan., pp. 75–78.

These are closely related to those which are in a state of uninterrupted activity, and which bear witness to it by visible glowing lava, such as Stromboli, and, under a very different form, Kilauea. The already mentioned Izalco was also not long ago in a condition similar to that of Stromboli.

Then follow those which are subject to frequent eruptions, such as Vesuvius or Aetna, or to less frequent eruptions, such as Ischia. Their number is very great, and still more numerous are those of which there is no certain record of eruptions since the dawn of history, and which have yet preserved their ash cones intact, such as the Puys of Auvergne or Rocca Monfina.

Then follow those which are so far advanced in a state of ruin that the skeleton of the partially destroyed ash cone is visible; to these belong, for example, Monte Venda in the Euganaean mountains, at the denuded base of which the lateral intrusions are revealed; and, according to Doelter's observations, certain eruptive centres on the Ponza Islands. Here the lava flows are already cut off from their place of issue.

I know of no basic volcanos with a visible skeleton, but there are numerous cases of the isolation of basic lava flows, which are associated with volcanos reduced to this or the following stage.

The erosion proceeds further, and the lateral intrusion or injection of lenticular masses of acid lava, visible at the foot of the Venda only on a small scale, is exhibited on a very large one, as in the Henry mountains, Sierra el Late, San Carriso, and other cases in Central North America.

The demolition still continues; in Predazzo, for example, it reveals above, on the summit of the mountains, lavas interstratified with Trias deposits, and below in the valley the lower portions of the funnel, which is filled with granitic and syenitic rocks, while on the walls the zones of contact are accompanied by the characteristic silicates. This exposure of the rocks far beneath the surface may occur on a line connecting several centres of eruption, as in the Hebrides, or it may extend so far that the continuity of the common fissure becomes manifest as in the Banat. Finally, the erosion may be so extreme that it leaves nothing but a cicatrice, such as the syenite belt of Brünn.

All the stages so far mentioned present either ejectamenta on the surface of the planet, caused by eruptions, which have forced them out from its interior, or the remains of the vents and fissures, through which these ejectamenta have made their escape. The destruction of the earth, however, proceeds further; denudation exposes to view masses which, at least in the majority of cases, did not reach the exterior in a molten incandescent state, but solidified beneath the surface as batholites, as mighty cakes of rock, a fact often brought home to us by a fragment of the ancient vault preserved on their summits as a mass of altered schist.

The ash cones of the present day thus bring us to the granite masses of the Erzgebirge, to the Drammen granite of Norway, and to a knowledge of the manifold variety in the mode of origin of the granite of the Alps.

Finally, this series of phenomena leads to the conception of subterranean cavities, formed by tangential pressure or by radial rupture; we have now to determine to what extent the actual structure of the mountains is in accordance with this hypothesis.

# CHAPTER V

## DIVERSITY OF THE MOVEMENTS

**Attempts to classify earthquakes. Earthquakes of volcanic origin, and those caused by dislocation. Earthquakes associated with flaws. Earthquakes associated with over-riding. Earthquakes caused by subsidence. Aetna, 1780, and 1874 to 1883. Different nature of volcanic earthquakes. The denudation series.**

Precise investigation shows us that a measurable displacement of any fragment of the rocky crust of the earth, with regard to another, whether it takes the form of elevation, subsidence, or horizontal displacement, has not yet been convincingly established. Two prominent examples, the formation of the Allah-Bund in the Rann of Cutch and the alleged repeated elevations of the west coast of South America, which are frequently cited in proof of such alterations, have already been discussed; and others, as we shall show later, will lead us to similar results. But if movements do not actually take place before our eyes, yet numerous dislocations show that they have often occurred on the grandest scale, and frequent earthquakes prove that they are not yet at an end.

The diversity of seismic movements in kind is very great; the phenomenon is, of its very nature, difficult to subject to the methods of exact observation, and the amount of systematic work devoted to it up to the present is very small. In treating of the nature of earthquakes it is therefore necessary to observe an unusual degree of reticence.

Of late years many attempts have been made to classify earthquakes according to their origin. R. Hoernes distinguishes earthquakes produced by *subsidence*, *volcanic* earthquakes, and *tectonic* earthquakes [1]. Toula adopts this classification, but proposes to call the two latter *dislocation* or *structural* earthquakes [2]. Lasaulx distinguishes between volcanic and non-volcanic earthquakes, and then divides the latter group into *subsidence* and *fracture* earthquakes. As a secondary phenomenon, Lasaulx mentions the group of *relais* earthquakes, that is, secondary concussions, which occur outside the immediate seismic area of a shock, and are started by its excitation in other seismic regions [3].

These are first and, as it were, tentative efforts to distinguish between

[1] R. Hoernes, Erdbebenstudien, Jahrb. geol. Reichsanst., 1878, XXVIII, p. 387 et seq.
[2] F. Toula, Ueber den gegenwärtigen Stand der Erdbebenfrage, 8vo, Wien, 1881, p. 54.
[3] A. v. Lasaulx, Die Erdbeben, in A. Kenngott, Handwörterbuch d. Mineralog., Geol. und Palaeontol., I, 1883, pp. 358–364.

the multifarious forms of the phenomenon, and if possible to more exactly define them. In these attempts, the essential point appears to me the separation from all others of those earthquakes, whether called dislocation or tectonic earthquakes, which accompany or precede an actual displacement of individual parts of the lithosphere.

On the supposition, which may be readily conceded, that no dislocation takes place without an earthquake, there must be as many kinds of dislocation earthquakes as there are of dislocations, and the same principles of division must obtain in both cases. According to this we should have to distinguish, at least in those typical cases in which the resolution of the telluric stresses is fairly complete, two main groups of dislocation earthquakes, namely, those which result from tangential forces and those which are caused by subsidence.

All those earthquakes which have been already described in the north part of the eastern Alps, as well as the earthquake of Sillein on January 15, 1858, in the region adjacent to the Carpathians, agree in presenting a major axis directed at right angles to the strike of the mountains. The movement produced, which in many cases has its epicentre close to the outer edge of the mountains, always travels in a straight line far into the mass of Bohemia, which lies across its course, and it is not seldom continued to Prague or Leitmeritz, while it may even reach Meissen in Saxony. This is true of all the shocks which have occurred along the Kamp-line since the year 1590, and also of the earthquake of Scheibbs of July 11, 1876. The analogy of the seismic lines with the class of dislocations which we call flaws, and Bittner's remark on the precise parallelism between the flaws and the Kamp-line, have already been mentioned. All these earthquakes must accordingly be regarded as flaw-shocks (Blattbeben).

The analogous earthquake of Belluno on June 29, 1873, will be discussed later.

If the Belgian earthquake of February 23, 1828, which though of moderate intensity was distinguished by the large area it affected, and by the fact that it followed closely the strike of the coal-field, did, indeed, as Lasaulx supposes, proceed from the faille du Midi (Fig. 17, p. 142), it might be regarded as an example of an *overthrust* or *over-riding* shock (Wechsel- oder Vorschubbeben)[1].

Generally speaking the seismic area of an overthrust shock is less sharply defined on the surface than that of a flaw-shock, which is characterized by the radial direction in which the seismic line proceeds from the mountain chain.

It is probable that the greater number of the earthquakes in the

[1] The references to this remarkable earthquake have been collected by Hoff, Gesch. der natürl. Veränderungen der Erdoberfläche, V, 1841, pp. 286-293.

northern half of the Alps are the result of tangential movements. Such earthquakes, as we have already said, appear to be very rarely accompanied by volcanic eruptions.

It was observed, when discussing the second group of dislocations, that the second component resulting from the contraction of the globe, the pull from above downwards, finds no expression in the nature of the disturbances which occur in the crust of the earth, but that the dislocations included in this group appear simply as manifestations of the force of gravity, and produce an impression as though parts of the earth's crust had collapsed by reason of their own weight and sunk into cavities, already existing beneath them, or as though the surface had sunk on a yielding substratum.

But here we enter upon a number of open questions, for this series of phenomena, especially the subsidence of large fragments of the earth's crust, brings us back to the as yet but ill defined, although well founded, hypothesis of the formation of large shallow cavities in the interior of the earth, to which Dutton has given the name of *maculae*: and it is precisely here, along lines of dislocation in these sunken areas, that together with earthquakes the majority of volcanic outbreaks occur.

The question then at once arises as to where the line must be drawn between earthquakes of dislocation and volcanic earthquakes; in theory the answer is easy, since explosive phenomena may be regarded as the characteristic sign of volcanic earthquakes, but it is not so easy in fact; an eruption pursues its course in a succession of stages, the movements in one stage may not resemble those in another, and over long extended lines earthquakes occur, which might easily be taken for dislocation earthquakes, but which merely characterize one phase of the volcanic eruption.

The great Calabrian earthquake of 1783, in which the seismic centres appeared first on one, and then on the other side of a peripheral fault-line, was a dislocation earthquake, and may be termed a *peripheral subsidence-earthquake*, as distinguished from the *radial earthquakes* of the same region: earthquakes which proceed from the region where the radial lines intersect one another, as in the Lipari Isles, we may speak of as *central subsidence-earthquakes*. The various fragments of a sunken area, moreover, may also experience shocks simultaneously, but in different directions. In any case the eruption of the volcano in dislocation earthquakes is a secondary phenomenon.

It is much more difficult to apply these distinctions to the continent of Central America. For although the subsidence of the Pacific region is clearly evident, and although the presence of a great volcanic zone is unmistakable, yet this region differs essentially from the south of Italy; it is distinguished, except at its north-west extremity, by the general and constant displacement of the volcanic activity along transverse lines,

towards the sunken area, while in the more restricted, plate-shaped area of subsidence in South Italy the phenomena do not manifest themselves along the radial lines in the same regular manner. In order to make clear the difference between the volcanic phenomena of Italy and those which occur along a radial line, we will cast a glance on the line which runs from Vulcano to Paternó and Mineo, passing through Aetna in an almost north-north-east to south-south-west direction.

For some time previous to the Calabrian earthquake of 1783, this line had given signs of unrest.

After a period of inactivity, which had lasted fourteen years, Aetna became the seat of repeated eruptions in the first half of the year 1780; on May 18, local shocks of great violence, which were compared with explosions, occurred on the coast between Taormina and Messina; in the month of June, Vulcano broke out with a deafening noise; on September 14, Patti, situated on the north coast, between Vulcano and Aetna, was convulsed by a violent shock of earthquake; on February 13, 1781, there was an earthquake in Messina; on May 4, while Aetna was still in activity, another shock occurred, directed from north to south, from Vulcano past Patti towards Aetna; later, on February 5, 1783, the great Calabrian earthquake commenced.

This line has been in activity since the year 1873. We possess accounts of the course of events in Vulcano by Mercalli and Piscone; the phenomena which presented themselves in Aetna and Sicily have been investigated in the most detailed manner by Orazio Silvestri [1].

Vulcano had been inactive since 1780, when in the month of July, 1873, it began to emit a continually increasing quantity of vapour. On September 7, a lofty column of steam and ash rose up, then followed rhythmical Strombolian eruptions which continued up to October 20; four great openings were formed in the northern part of the crater. Vulcano then remained moderately active until the middle of the following year, 1874.

On August 29, 1874, Aetna broke out. The summit of the mountain was cleft from the *Cratere elliptico* towards the north-north-east for a length of 5 kilometers. A vast column of smoke poured forth; ashes and scoria were ejected; for seven hours, as Silvestri says, the peculiar roaring was heard which accompanies the welling up of lava. Then in a completely unexpected manner the signs of the approaching eruption

[1] O. Silvestri, Ueber die Eruption des Aetna am 29. August 1874, transl. by G. v. Rath, Neues Jahrb. Mineral., 1875, p. 36, and by the same, Sulla doppia eruzione e i terremoti dell' Etna nel 1879, 2ª ed., ampliata del 1º rapporto present. al R. Governo, 8vo, Catania, 1879, 46 pp., tav.; by the same, Lettera all' ill. Prof. L. Palmieri, in Boll. Vulc. ital., VII, 1880, pp. 9-12 and pp. 82-86; further: Sulla eruzione dell' Etna scopp. il dì 22 Marzo 1883; rapporto al R. Governo, 8vo, Catania, 1883; for the behaviour of Vulcano during this time: G. Mercalli, Contribuz. alla geol. delle Isole Lipari, Atti d. Soc. Ital. di Sc. nat., Milano, 1879, XXII, pp. 367-380.

began to diminish, and on the next day, August 30, the paroxysm appeared to be at an end. For a considerable period violent earthquakes continued at the northern foot of the mountain.

We now reach the next phase. This began on October 4, 1878, with a violent earthquake at Mineo, at the southern extremity of the radial line. Further shocks followed; early in December eruptions of gas and mud, lasting a long time, took place from the mud-volcanos of Paternó, which lie on a straight line between Mineo and the summit of Aetna. The activity of Vulcano, which had not entirely ceased since 1873, increased from January 6, 1879. On May 26, repeated earthquake shocks were felt at the southern foot of Aetna, and towards evening black columns of steam and ash were seen to ascend from the summit of the mountain, both from south-south-west and north-north-east, while white vapour rose from the main crater. The whole upper region of the volcano was cleft across in the direction of the radial line from south-south-west to north-north-east for a distance of 10 kilometers; the cleft opened up with a slight S-shaped curve right through the middle of the main crater, following the course of the fissure of 1874. Silvestri made a detailed study of the eruption, which he followed with admirable courage and sagacity.

Between June 6 and 7 the eruption might be considered to have come to an end. Quite outside the scene of these events, far below, at the eastern foot of the mountain, near the threshold of the Val del Bove on the seaward side, a slight shock had been felt on June 1. Although the eruption was over, the shocks continued to succeed each other here until, on June 17, an extremely violent vertical concussion affected this apparently outlying region. Persons in the open country felt as though they had made a leap. Several towns were seriously damaged. The main axis of the area of concussion, about seven kilometers long, was directed from east-south-east towards the summit of Aetna [1].

The eruptions at Paternó increased; on December 13, 1879, a violent earthquake again occurred in the south near Mineo.

Silvestri had already concluded from these facts that a fissure must exist in the interior of the earth, traversing Aetna from north-north-east to south-south-west and that its course is marked out by the most northerly of the parasitic cones situated near the village of Mojo, by the main crater, and the mud-volcanos of Paternó and Mineo. This supposition received additional confirmation when, on March 22, 1883, the mountain opened up along a fissure five kilometers long, situated beneath Monte Concilio, further to the south, and lower down than on previous occasions, but again directed from south-south-west to north-north-east; this time also the quantity of lava

[1] 'Il movimento del suolo fu come una spinta così veemente, che la gente che era per le strade e per le campagne ebbe la coscienza di aver fatto in quel momento come un salto da terra.' Silvestri, Rapporto, p. 39.

which escaped was by no means great. The activity of Vulcano and its situation suggest that this cleft may be a continuation of the southern radial line of the Lipari Isles.—

These details make clear the great difference between a dislocation earthquake due to tangential stress, such as the flaw-shocks of the northern Alps, and the phenomena which manifest themselves on the radial fissure of a sinking area.

In the later eruptions of Vesuvius it was always possible to distinguish a longer or shorter period of preparation. Silvestri lays particular emphasis on the fact that the last great eruptions of Aetna have invariably been preceded by a longer or shorter period of Strombolian, i.e. rhythmical activity. This seems to indicate that it is not a question of the relative movement of great fragments of the earth's crust, but of the gradual and temporary reopening of the canals, choked with scoria, which extend along the volcanic fractures.

In other volcanos, however, cases have been observed of a more tranquil discharge and outflow of great quantities of lava, and Dutton has described a remarkable example of this kind in Mauna Loa. Here the outbreak of lava takes place suddenly from radial clefts, the glowing stream spouts up at first to a considerable height, and then flows away; one of the three streams of 1881–1882 attained a length of eighty kilometers; but no earthquake, no violent tremblings of the mountain, no outburst of clouds of water vapour, not even the formation of ash cones as on Kilauea, accompanied the phenomenon[1]. If then we have reason to believe that dislocations are always accompanied by earthquakes, this is by no means the case with eruptions. A closer comparison of Silvestri's description, particularly as regards the behaviour of the mud-volcanos of Paternó, with Dutton's statements, lends support to the opinion that the noise of the eruption, the ejection of scoriae, and even certain earthquakes are mainly to be ascribed to water vapour.

Of particular importance appear to me the earthquakes which sometimes occur *after the eruption*, in regions lying at a distance from the main area of shock, such as those which were felt at the eastern foot of Aetna in June, 1879, following upon a temporarily suspended eruption.

The disturbances move on a long line, from Vulcano to Mineo; only at one spot, on the flanks of Aetna, high above Vulcano, and above the other convulsed regions, lava pours out and explosions ensue. But far below, at the foot of the mountain, shocks of earthquake take place after the conclusion of the explosions. All the concussions on this long line might be regarded as preparatory to the eruptions; but this conception will not apply to these later shocks.

[1] C. E. Dutton, Recent Exploration of the Volcanic Phenomena of the Hawaiian Islands; Am. Journ. Science, 1883, 3rd ser., XXV, p. 222. The whole of the mighty cone of Mauna Loa is built up, not of ashes, but of vesicular lava.

There is yet another group of earthquakes, sometimes very violent, sometimes sharply circumscribed in space, which have their origin in some cases in the neighbourhood of active volcanos, such as the earthquake of Ali, not far from Taormina in Sicily, May 18, 1780, or that of Casa Micciola on Ischia, March 4, 1881; in others in volcanos recently extinct, as the numerous earthquakes which have proceeded from the Albanian mountains or Monte Vulturo; or in yet others in long extinct eruptive masses, such as that of May 21, 1882, from the Kaiserstuhl in the Breisgau [1].

These phenomena have a number of characters in common, and I do not know whether to class them as explosive shocks or as subsidence earthquakes. Further observations are requisite for a satisfactory solution of this question.—

We attempted in an earlier chapter to determine a denudation series of volcanos. Starting from the youngest ash cones of the present day we arrived at those in which the skeleton is exposed to view (Venda, Ponza islands), and traces of lateral acid intrusions are perhaps already visible in the basal structure (Venda); these invite comparison with the great American laccolites (Henry mountains and others). We saw that in the eruptive centres, which had been more deeply eroded, rocks of ancient type (syenite, quartz-diorite, granite) are to be observed, within the flows enveloping them, in the lower part of the pipe (Hebrides, South Tyrol); the remains of the flows then disappear, the section of the eruptive centre grows longer, and the volcanic cleft becomes more and more continuous (Banat).

It is this phase which furnishes material for comparison with the observations of Silvestri on the activities associated with the great cleft that traverses Aetna.

At length, as the destruction of the outer envelope of the earth extends deeper, there stand revealed the elongated cicatrices, and those great swollen cake-like masses of intrusive granite or syenite, which bring about the metamorphosis of the sedimentary beds forming their roof; and by these we are put upon the trail of a series of great abyssal phenomena.

These phenomena seem to stand in some causal connexion with the absence of the tangential component in the dislocations of our mountains—with the passive subsidence of extensive plates and great fragments of the crust into the profound depths below.

In the next part we will briefly survey, in the light of our present knowledge, the structure of the most important mountain chains of the earth, and so proceed to inquire to what extent the resolution of the stresses in space, which result from a diminution in the volume of the planet, finds expression in its outer aspect.

[1] A. Knop, Das Erdbeben im Kaiserstuhl im Breisgau am 21. Mai 1882; Beitr. z. naturwiss. Chronik des Grossh. Baden, 1881–1882; from the Verh. Karlsruh. naturwiss. Vereines, 1883, pp. 1–6, and plate.

# PART II

# THE MOUNTAIN RANGES OF THE EARTH

## *CHAPTER I*

## THE NORTHERN FORELAND OF THE ALPINE SYSTEM

**The Russian Platform. The Sudetes. The Franconian-Swabian area of subsidence. Ries and Höhgau. The horsts. Quartz dykes in the horsts. Zigzag outlines. Jurassic relicts of the Sudetes. Relation of the Alpine system to its foreland.**

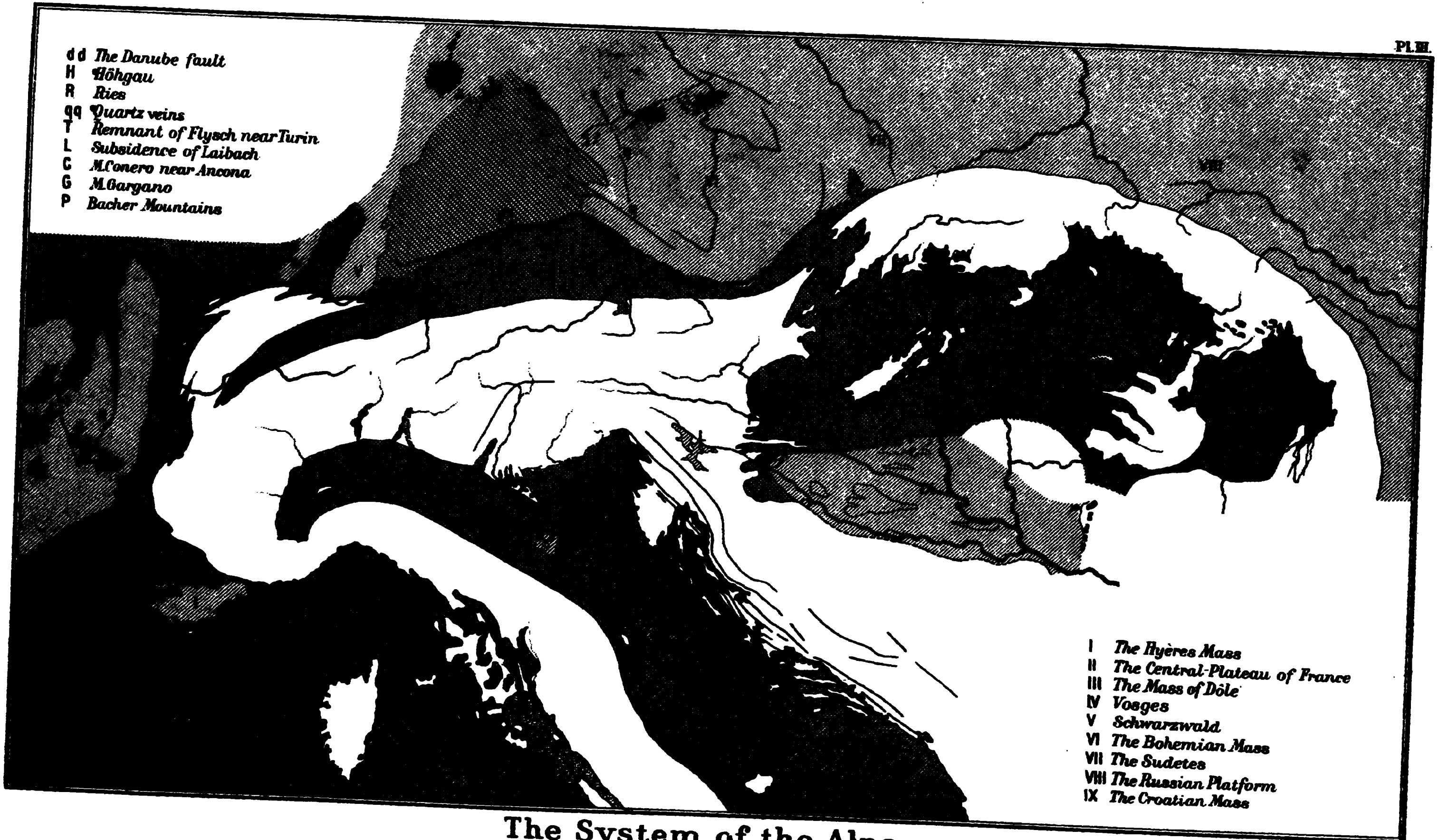
The earthquakes which are propagated from the northern border of the Alps to the granite mountains of Bohemia travel from one fragment of the earth's crust to another (p. 78, Fig. 3). The difference in the structure and stratification of the two regions is extraordinarily great. The uniform structure of the outer border of the Alps and of the Carpathians, from Switzerland through Bavaria, Austria, Moravia, Silesia, and Galicia, is just as striking as the diversified outline of the masses bounding it on the north. Nevertheless the contour of the Alpine system and the fold on its outer border evidently stand in a certain relation to this northern foreland.

In order to understand the structure of the Alpine system it is therefore necessary to know that of this northern foreland as well, and if, on the one hand, it has hitherto been admitted that the contour of the Alpine system has been determined by the foreland, it remains, on the other, an open question whether the formation of the Alps may not also have exerted an influence on the structure of the foreland.

The northern foreland of the Alps falls into three parts, differing widely from one another. These are, proceeding from east to west: the Russian Platform, the Sudetes, and the mountain-core of Central Europe. Under the last term I include the mass of Bohemia and all the ancient masses occurring to the west of it in the foreland of the Alps: namely, the Schwarzwald, the Vosges, the small mass near Dôle, the Central Plateau of France, and the Iberian Meseta.

### A. *The Russian Platform.*

The most singular portion of the foreland is the *Russian Platform.* To find a starting-point for its description we must proceed far to the north. Let us examine Grewingk's map of the Baltic provinces. Granite and gneiss form the whole of Finland and the north coast of the Gulf of Bothnia. On the south coast the lower divisions of the Silurian appear, horizontally




The System of the Alps.

stratified; the upper stages follow to the south and include the northern part of Lake Peipus and, towards the west, the island of Oesel. Then follows likewise, with almost horizontal bedding, the Old Red sandstone of the Devonian system; this extends as far as the southern end of Lake Peipus and forms almost the whole coast of the Gulf of Riga. Still further to the south lie the middle and upper divisions of the Devonian, extending over wide areas, while towards the north-west of the province of Kovno the Zechstein and the Jurassic beds of Popilany rest in transgression on the horizontal platform of the Silurian and Devonian strata [1].

No mountain slopes, comparable to the border of the Bohemian plateau, face the eastern Carpathians; the plain formed of loess, of different deposits of the younger Tertiary period, and of the middle and upper Cretaceous, stretches away far and wide. The course of the Dniestr and its tributaries reveals, however, beneath this mantle of younger rocks the continuation of the Palaeozoic platform, which we observed far in the north. The red sandstone masses of the Devonian, the remarkable fish remains, the marine mollusca of the Silurian, and the horizontal stratification have long since placed the correspondence of this basement with the great Russian Platform beyond all doubt. The beds are never folded and dip only very gently to the south-west. Malinski and Barbot de Marny have recently traced the continuation of these strata in the adjacent parts of south-western Russia, and Alth has combined all the older and more recent observations, both Austrian and Russian, in a most instructive study [2]. This has been supplemented and completed by the works of Paul [3] and the palaeontological observations of F. Schmidt [4]. Finally Alth himself has since established the remarkable fact that towards the west an upper Jurassic limestone formation is intercalated between the Old Red sandstone and the Cenomanian, a transgression of western character [5].

The exposure of ancient rocks is, it is true, confined to the river-valleys, but a combination of observations makes it possible nevertheless to recognize the distribution of the various formations in its main outlines. The granite plateau which extends over large areas at the Bug and continues into the government of Kherson forms the foundation; it is visible on the Dniestr

[1] C. Grewingk, Geogn. Karte der Ostseeprovinzen, Liv-, Esth- und Kurland; Archiv für Naturkunde, Dorpat, 1879, Bd. VIII.

[2] A. v. Alth, Ueber die palaeozoischen Gebilde Podolien's und deren Versteinerungen, Abhandl. geol. Reichsanst., 1874, VII, in particular pp. 1–21, and supplemented by Die Gegend von Nizniow und das Thal von der Zlota Lipa in Ostgalizien, Jahrb. geol. Reichsanst., 1877, XXVII, pp. 319–340.

[3] Paul, Grundzüge der Geol. der Bukowina; Jahrb. geol. Reichsanst., 1876, XXVI, pp. 328–330.

[4] F. Schmidt, Einige Bemerkungen über die Podolisch-galizische Silurformation und deren Petrefacten; Bull. Acad. St. Petersb., 1875.

[5] A. v. Alth, Die Versteinerungen des Nizniover Kalksteines; Beitr. zur Palaeont. von Oesterr.-Ung. von Mojsisovics und Neumayr, 1881, I, p. 183 et seq.

as far as Jampol below Mohilew, while the extreme limit within which granite occurs runs from this point in a north-westerly direction towards Proskurow on the Upper Bug, and then to the north-north-east towards Novgorod-Volynsk in Volhynia. West of this line we encounter Palaeozoic beds almost horizontally stratified, and more and more recent subdivisions appear as we proceed towards the west [1]. Near Jampol, sandstone, representing the oldest member of the Silurian, lies on the granite; this is followed by higher members of the series, which occur near Mohilew, Kamenetz-Podolsk, on the Austrian frontier, northwards as far as Tarnaruda; and within the frontier, on the Dniestr to above Zalescyki. Along the tributaries of the Dniestr, which all come from the north, the exposure of these strata depends on the extent of the erosion. The highest divisions of the Silurian are followed towards the west by the red Devonian sandstone; it is visible on the Dniestr to above Nieznow, on the Zlotalipa and in the valley of the Sereth to within eight kilometers below Tarnopol; then it disappears beneath much younger deposits.—

There thus lies, beneath the plain of eastern Galicia, a part of that remarkable platform which from the most distant times has preserved its horizontal stratification over an area extending from the south of Sweden through northern and central Russia and far away to the east, and which here too in the bed of the Dniestr shows no appreciable displacement of its strata.

Between the Dniestr near Zalescyki and the outer border of the Carpathians, which is formed of folded Neocomian beds, flows an important river, the Pruth, but its valley, although eroded to about the same level as that of the Dniestr, reveals nothing but Tertiary sand and clay.

The continuation of the Palaeozoic deposits is sought in vain, and not even Cretaceous is to be seen.

Alth supposes that a great subsidence must have taken place on the eastern border of the Carpathians, in consequence of which a broad gulf many miles in length was formed, and subsequently filled by Tertiary deposits [2]. Paul even thought it not impossible that we might find in the crystalline schists of the Carpathians the metamorphosed equivalents of the Silurian deposits of Podolia [3].

However this may be, so much is certain, that this whole series of thick

[1] I am not yet clear as to the arrangement of the beds in Volhynia. Ossowski's beautiful geological map of Volhynia (fol., Paris, 1880) gives Cretaceous and Tertiary towards the west; but towards the east, on the other side of the river Slucz and in the region of its springs, azoic quartzite, and then limestone and shales. The quartzite, however, rests directly on granite.

[2] A. v. Alth, Palaeoz. Geb., p. 4; a section from the Pruth to the Dniestr, but chiefly with reference to the Tertiary formations, is given by Petrino, Verhandl. geol. Reichsanst., 1875, p. 218.

[3] Paul, Geol. Bukow., p. 330.

deposits, which extends so far to the north and north-west, is here suddenly lost to view.

In the same latitude as the Silurian basin of Bohemia, and even still further to the south, *Eurypterus Fischeri*, *Illaenus Barriensis*, *Phacops Downingiae*, and other fossils characteristic of the north, may be collected on the Dniestr. Yet more striking is the presence of the Old Red sandstone, which may be followed for more than thirty degrees of latitude towards the north, Nathorst having lately pointed out its equivalent in Spitzbergen [1]. From Spitzbergen it is continued across the Orkneys to Scotland and Wales. Certain patches of old sandstone in Norway may possibly be referred here. The most southerly districts in which Old Red sandstone occurs are those facing the Carpathians, and from here we must again travel far to the north in order to find the continuation of the Scandinavian strata on the Gulf of Riga. Thence it is further continued to the east and north-east towards the White Sea, as though the Scandinavian Finnish mass were surrounded by a great girdle of Old Red sandstone [2].

If, from the border of the Carpathians near Kutty, we travel to the north-north-east, we reach, at a distance of about 34·5 kilometers, the middle of the Pruth valley, above Sniatyn, and after another 25 kilometers the Palaeozoic deposits near Zalescyki. Over these 25 kilometers this portion of the Russian platform, owing either to a continuance of a gentle inclination to the south-west (which it already possessed in places) or to a flexure or fracture, must have been sunk so deep that it is no longer visible in the valley of the Pruth, and the subsidence is probably continued still further towards the Carpathians, and even beneath them.

All these circumstances lead us to the conclusion that *a part of the Russian Platform has been overthrust by the folds of the Carpathians.*

## B. *The Sudetes.*

The horizontal stages of the Russian Platform disappear towards the west beneath the plain; it is doubtful whether they cross the Bug under a covering of younger deposits, but it is certain that to the east of this they do not reach the river San.

At a considerable distance to the east of this river, near the town of Lubaczow, Hilber has observed in two places an outcrop of steeply upturned beds of grey slate [3].

[1] A. G. Nathorst, Ueber die wissenschaftl. Resultate der letzten schwedischen Exped. nach Spitzbergen (trans. by Th. Fuchs); Verhandl. geol. Reichsanst., 1883, p. 25.

[2] Godwin-Austen, Jones, Ramsay, Geikie deny the marine origin of the Old Red, and regard Scandinavia, with its continuation to the Hebrides, as a very ancient continent: Geikie, On the Old Red Sandstone of Western Europe, Trans. Roy. Soc., Edinb., 1878, XVIII, pp. 346, 350.

[3] V. Hilber, Geol. Aufnahmen um Lubaczow und Sieniawa in Galizien; Verhandl. geol. Reichsanst., 1882, p. 307.

In the south of Radom, near Sandomir, Kielce, and Chiencing, there rises a small independent mountain chain, which we will call, with Pusch, the Sandomir mountains. It is composed, as F. Roemer and Hempel have shown, of a number of folds striking to the east or east-south-east, and is continued, according to Tietze's observations, into Austrian territory, near Gorzyce[1]. The whole series of the Trias and a part of the Jurassic formation are present, and have been involved in the folding of the chain. The lowest member is, according to Zeuschner, Silurian slate containing Graptolites, for the mighty masses of quartzite which project in the anticlinals appear to belong to the lower Devonian. Zeuschner has also found a rich middle Devonian fauna, corresponding to that of the Eifel limestone[2], and F. Roemer has recognized besides an upper Devonian fauna which coincides with that of the Goniatite schiefer of Büdesheim and the Cypridina schiefer of Nassau[3]. The Carboniferous system does not seem to be represented, since Zechstein, with *Productus horridus*, and then the Trias, succeed the Devonian.

Here we have no longer the stratification and structure of the Russian Platform, and although in the extreme north the schists of Domanik constitute an equivalent to the Goniatite schiefer of Büdesheim and Devonian limestone with *Stringocephalus Burtini* still occurs in the Ural, yet what is known of the Sandomir mountains accords so completely with the structure in the west as far as the Sudetes, that the boundary line must be sought to the east of the river San.

In this region, which extends far to the west, ancient stratified systems do indeed now and again appear; for instance, middle Devonian and Carboniferous limestone near Debnik, north of Krzezowice, Stringocephalus

[1] F. Roemer, Geogn. Beobacht. im polnischen Mittelgebirge, Zeitschr. deutsch. geol. Ges., 1866, XVIII, pp. 667-690, pl. xiii; J. de Hempel, Descr. géol. des environs de Kielce, de Chenciny et de Malagoscz, situés au centre de la Pologne, Ann. des Mines, 1867, 6th ser., XII, pp. 141-183, with map; E. Tietze, Verhandl. geol. Reichsanst., 1883, p. 31. The neighbourhood of Chmielnik and Pinczow on Russian territory is represented on the geological map of a part of the Gouvern. Kielce by S. Kontkiewicz, Sprawozdanie z Badan geol., &c., Pamietn. Fizyjgraf. Warszawa, 1882, II, tab. x.

[2] Zeuschner, Ueber das Vorkommen von *Diceras arietina* in Korzetzko bei Chenciny, Zeitschr. deutsch. geol. Ges., 1868, XX, pp. 576-580; Ueber die eigentümliche Entwicklung der Triasformation zwischen Brzeziny und Pierzchnicau, &c., tom. cit., pp. 727-740, pl. xv; Ueber die neuentdeckte Silurformation von Kleczanow bei Sandomierz im südl. Polen, op. cit., 1869, XXI, pp. 257-262; and Geogn. Beschr. der mittleren devonischen Schichten zwischen Grzegorzowice und Skaly-Zagaje bei Nowa Slupia, tom. cit., pp. 263-274; further, Ueber den silurischen Thonschiefer von Zbrza bei Kielce, tom. cit., pp. 569-573, and map. I have still some doubt whether according to Hempel's representation the Mesozoic beds have shared all the movements of the older formations. J. Trejdosiewicz, Opis badan geol., &c., Sprawozd. Komis. fizyjogr., XIII, Krakau, 1879, has also observed middle Devonian limestone near Zbrza, and assigns the quartzite of this region to the lower Devonian.

[3] F. Roemer, Geogn. Beobacht., p. 675; Leth. Geogn., 1880, I, pp. 23, 49.

limestone near Siewersz, and Devonian slate near Tost, north of Gleiwitz, until finally on the other side of the upper Silesian coal-fields we reach the slopes of the Sudetes.

Here we are concerned only with the *southern part of the Sudetes.* I should far exceed the limits of this work if I were to enumerate all the distinguished investigators to whom we owe our knowledge of the structure of this mountain chain. For the Austrian region I will only mention H. Wolf and D. Stur[1]; for the border of the Carpathians, the district of Cracow, Hohenegger and Fallaux[2]; for Upper Silesia and the adjacent parts of Poland, F. Roemer[3].

The southern part of the Sudetes presents a purely monoclinal structure; descending from its highest summits we meet as a rule with deposits becoming more and more recent towards the east and extending far into the plains of Poland. The oldest divisions of this series which rise to the greatest heights have also as a rule the steepest dip; the next succeeding members as far as the Coal-measures often exhibit subordinate folds and fractures, owing to which their thickness, already considerable, appears yet further increased. The more recent stages are horizontally bedded in the plain, while further to the north indications are not wanting that great folding took place after the Cretaceous period.

A closer examination of this great series, which is inclined to the east, shows, however, that it is not complete; several members, such as the Lias, Neocomian, Gault, and Eocene, are wanting; every gap is followed by a transgression, which took place over the widely denuded surface of older formations; and since the latter did not present horizontal surfaces to the erosion, Bunter sandstone is found resting here, for example, on the Culm and there, but a little way off, on the Coal-measures, and so with other formations. The movements which caused the repeated abrasion and transgression were evidently very uniform and similar.

The eastern slope of the range, from its summit to the Coal-measures of the plain, consists for a breadth of several miles of Devonian and Culm. On rocks, which are probably Archaean, lie lower Devonian quartzites containing *Homalonotus crassicauda, Grammysia Hamiltonensis,* and *Spirifer macropterus.* This zone extends approximately north and south in the neighbourhood of Zuckmantel and Würbenthal, and then turns off to the south-south-west. In this direction the lower Devonian is con-

[1] The results of these works, as far as they refer to the Devonian and Carboniferous, have been united in a detailed representation by D. Stur, Die Culmflora, I, pp. 91–103, II, pp. 317–366; Abhandl. geol. Reichsanst., 1875–1877, VIII.

[2] L. Hohenegger, Geogn. Karte der Nordkarpathen in Schlesien, &c., with text, Gotha, 1861; by the same, Geogn. Karte des ehemaligen Gebietes von Krakau, zusammengest. von Corn. Fallaux, Denkschr. k. Akad. Wiss. Wien, 1866, XXVI.

[3] F. Roemer, Geol. von Oberschlesien; Geogn. Karte von Oberschlesien, in 12 sheets, 1870.

tinued for a long distance and even reaches, near Petrowitz, east of Raitz, north of Brünn, the cicatrice which sharply separates the Sudetes from the Bohemian mass. This cicatrice is formed by the main boundary fracture, here distinguished by an intrusion of syenite.

The next zone towards the east is of middle Devonian age. From Bennisch to Sternberg it is distinguished by an outcrop of ironstones, then by tuffs, amygdaloidal diabase, and subordinate calcareous beds, the age of

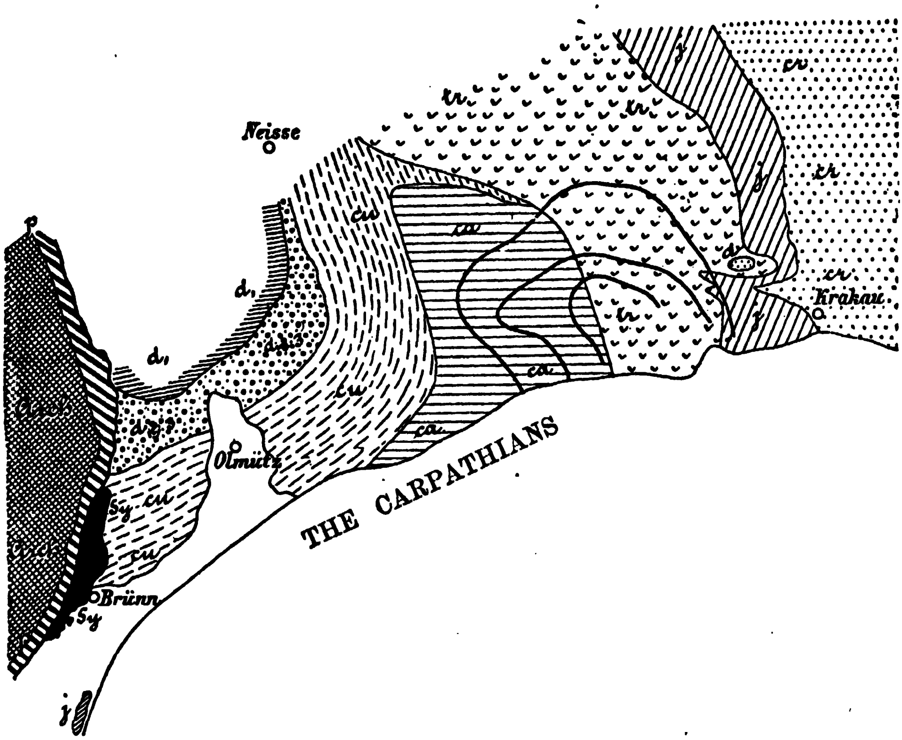



Fig. 24. *The foreland of the Western Carpathians* (based chiefly on the works of F. Roemer, Hohenegger, and F. v. Hauer; the Coal-measures after Jicinsky). All the transgressive strata and the Miocene and more recent deposits are supposed to be removed.
*Arch* = Archaean rocks; $d_1$, $d_2$, $d_3$ = Devonian; *cu* = Culm; *ca* = Carboniferous; *p* = Rothliegende; *tr* = Trias; *j* = Jurassic; *cr* = middle and upper Cretaceous; *sy* = Syenite.

which is determined by *Phacops latifrons*. Further to the south the zone consists only of limestone, and it also reaches the syenite to the north of Brünn while retaining a considerable breadth [1].

Then follows the broadest of these zones, the Culm with its slate

[1] Of late the view has again been put forward that the narrow band of limestone situated to the west of the syenite at Schloss Eichhorn is to be assigned to the Devonian (C. v. Camerlander, Verhandl. geol. Reichsanst., 1883, p. 57). From this it would follow that the boundary of the Sudetes is indicated at this point not by one continuous fault, but by two or more parallel faults. This would involve no further alteration in the description attempted here.

quarries. Stur has distinguished three horizons within this zone, the rocks of which are very various. *Posidonomya Becheri* and *Archaeocalamites radiatus* are the most important fossils. This zone advances towards the east near Hultschin in an obtuse angle, and there the steeply inclined strata may be seen in contact with the succeeding Coal-measures. In its prolongation to the south and south-west the *eastern border of the zone comes south of Weisskirchen into immediate contact with the outer border of the Carpathians.* The contact of the two chains is so close that

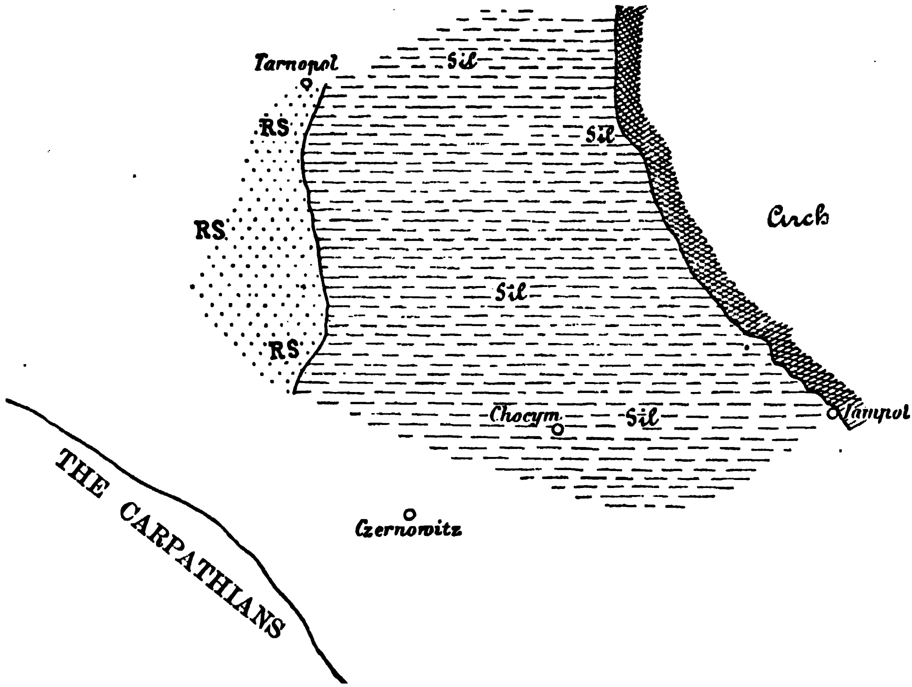



FIG. 25. *The foreland of the Eastern Carpathians* (based chiefly on the works of F. v. Hauer and Alth). The Cretaceous transgression, the Miocene, and more recent deposits are supposed to be removed.
*Arch* = Archaean rocks; *Sil* = Silurian; RS = Old Red sandstone.

the European water parting falls completely within the Culm zone of the Sudetes.

This zone is the last which is continued to the south of Weisskirchen as a chain; it forms the outer border of the heights which run down to Brünn. *All the succeeding divisions of the Sudetic series disappear between this place of contact and the neighbourhood of Cracow.*

Near Hultschin, as we have said, the upper strata of the Culm are followed by the Coal-measure series. The yielding nature of most of these rocks prevents their forming mountain ranges, and the result is a plain interrupted by scattered groups of hills. Nor do they form a zone striking

parallel to the Sudetes like the Devonian and the Culm far in the north, but, as F. Roemer has shown in detail, a series of outcrops of the Culm, having the form of a broad crescent, advances from the projecting parts of the chief masses past Hultschin and Katscher, to the east of Lobschütz, to the north of Kosel, and thence towards Tost. This line, together with the outcrops of Devonian limestone near Siewerz, and of Devonian and Carboniferous limestone north of Krzezowice, surround the area within which Coal-measures are known [1].

It will be seen that this curve is closed on the west, north, and east; but towards the Carpathians it is open. Herr Jicinsky, Director of Mines, has attempted by means of observations made in the mines to establish the continuity of the most important seams throughout the whole coal-field, and here again has obtained a series of great crescentic curves, which are continued beneath the Trias and open towards the Carpathians [2].

These facts seem to me to prove that *the Silesian coal-field is actually continued beneath the Carpathians.*

Hochstetter long ago put forward this view [3], and personally I have always shared it [4]; Stur [5] based his arguments on the same hypothesis, and Jicinsky has indicated the probable extension of the coal-seams beneath the Carpathians by dotted lines, and based on this a hypothetical section. But since these Carboniferous deposits rest conformably on the Devonian and the Culm of the Sudetes, and the difference in the form of the ground is only to be ascribed to the greater destructibility of the Coal-measures, we must regard the latter as a normal constituent of the Sudetes themselves, and thence it follows that the folds of the Carpathians may well have been packed against the upturned shales and sandstone masses of the Culm zone, while they have been driven over the low-lying surface of the Coal-measure region, and that in fact a portion of the Sudetes lies under the Carpathians.

Galleries have been excavated, for example, near Schönhof, close up to the edge of the Flysch zone of the Carpathians, and have even been bored in coal near Hustopec, to the north of the contact of the Culm and Flysch, near Weisskirchen. There a bed of coal was indeed found, but further exploration showed that it was enclosed in a very large isolated block of crushed Carboniferous deposits. As a rule, so far as we can judge from

[1] F. Roemer, Geol. von Oberschlesien, Atlas, index map, sheet 1.

[2] W. Jicinsky, Der Zusammenhang der mähr.-schles. und der preuss.-schles. Kohlenformation, in the Oest. Zeitschr. für Berg- und Hüttenwesen, 1877, pl. ix; by the same, Der Zusammenhang der einzelnen Flötze und Flötzgruppen im Ostrau-Karviner Steinkohlenreviere, op. cit., 1880, p. 409 et seq., pl. xvii.

[3] F. v. Hochstetter, Ueber das Vorkommen von Erdöl und Erdwachs im Sandecer Kreise in Westgalizien; Jahrb. geol. Reichsanst., 1865, XV, p. 206.

[4] Entstehung der Alpen, p. 71.

[5] D. Stur, Culmflora, pp. 319, 320.

existing exposures, the disturbances and fractures in the Coal-measures are, strange to say, inclined more steeply and violently towards the Sudetes than towards the Carpathians.

In spite of the great thickness of the Coal-measures—in the Austrian area estimated at several thousand feet—I do not believe that they were deposited in a basin, corresponding to that in which they at present lie; but I regard them as the remains of a much more extensive deposit, which have been protected, in a broad synclinal, from the great pre-Triassic denudation. This levelled the whole country at the time of the advance of the Bunter sandstone, exposing the anticlinal of the Culm, near Tost, and destroying the Permian deposits, of which only isolated traces are now visible.

Over these Palaeozoic deposits of the Sudetes there lies a most varied series of Mesozoic marine formations, with a very gentle dip to the east or north-east. The course of their western border is determined by the amount of erosion which they have themselves undergone, that of the visible eastern border by the denudation of the overlying, next younger stage. This is the origin of those parallel or concentric lines bounding the stratified formations on geological maps, which have so often been regarded as indications of subsidence, as for example in the basin of Paris.

This horizontal bedding is interrupted, at least as far as my observations extend, by a single important disturbance only; as to the relations of this to the general structure of the country I have been unable, in spite of repeated visits to the district, to come to any definite conclusion. The disturbance is a synclinal or trough fault lying transversely across the strike of the Mesozoic girdle and involving all the strata, including the Cretaceous; its axis lies somewhat north of Cracow and strikes in a west-north-west direction past Trzebinia towards Myslowitz (Fig. 24); it is at first fairly broad, then becomes narrower and steeper, and appears near Myslowitz to pass into simpler fracture. It is possible that a second dislocation of the same kind branches off from the first in the direction of Trzebinia-Chrzanow. With this exception the course of the Mesozoic zones is very regular and but little disturbed by protruding hillocks of ancient formations.

The Trias zone is resolved towards the west into a number of isolated outliers; in the north it dips, according to Roemer's observations, somewhat to the west of the Wartha beneath the middle Jurassic; it is affected by the above-mentioned disturbance of Cracow-Myslowitz, and on the south of this disturbance sinks in face of the Carpathians towards the Vistula, thus forming the chain of heights between Alwernia and Chelmek. The bedding here appears to be quite horizontal. The foot of the slope, crowned by the picturesque ruins of the fortress of Lipowec, is formed of Bunter sandstone. The foot of the Carpathians lies on the other side of

the Vistula, and is here, according to Hohenegger, formed of folded Nummulitic deposits. The distance between the foot of the two chains is 9·5 kilometers [1].

Above the Trias formation is the Rhaetic stage, only locally and feebly represented; the Lias is not to be seen; in the north argillaceous beds with *Perisphinctes Parkinsoni*, in the south the oolites of Balin with *Stephanoceras macrocephalum* extend over the Keuper; above these oolites a blue clay with *Belemnites semihastatus* occurs in the south, then follow the rocks of white Jurassic limestone which from Czenstochau onwards form a continuous chain—a very prominent feature in the landscape—extending along the eastern side of the Wartha past Olkusz to Cracow, and thence close to the foot of the Carpathians. To the east they dip, near Lelow and in the neighbourhood of Cracow, beneath a continuous mantle of Cenomanian. These Jurassic limestones withstand the effects of denudation better than the sandstones and clays of the lower stages of the Mesozoic series and even than the limestone beds of the Trias, which are intercalated between strata of less resistance. This is the obvious explanation of the fact that the Jurassic limestone can be followed across the valley of the Vistula, right up to the border of the Carpathians.

The Jurassic chain, where it is broken up into isolated hills, between Mirow and Podgorze, facing the Carpathians, attains a very considerable breadth. Between Tyniec and Podgorze it crosses the Vistula; several smaller masses rise from the alluvial ground, and the last hill, near Kurdwánow, to the west of Wieliczka, lies only two kilometers from the edge of the Carpathians, and stands already within the border of Tertiary clay containing sulphur and salt, which near Wieliczka itself is thrust by the Carpathians over to the north in great folds [2].

This very remarkable junction shows that the Jurassic zone which comes down far from the north-west, suffers no deviation in the neighbourhood of the Carpathians, but dips beneath these mountains.

Above the Jurassic, the Neocomian and Gault are absent. The Cenomanian stage, as may be seen in so many places, extends transgressively far over the older beds, and great isolated patches appear even to the west of the Trias zone near Oppeln, and directly upon the Culm zone near Hotzenplotz. This transgression reveals how great and extensive the erosion which preceded it must have been. The Culm-shales already lay exposed, the Trias must have been removed over a large part of the coal-field, and there is little doubt that at the time when the Miocene deposits near Wieliczka were driven forwards by the Carpathians, the erosion, not

[1] L. Hohenegger's map of Cracow shows these conditions with great clearness.

[2] Bemerkungen über die Lagerung des Salzgebirges bei Wieliczka; Sitzungsber. k. Akad. Wiss. Wien, 1868, Bd. 58, 1. Abth., p. 544.

only of the Carboniferous, but also of the Trias and Jurassic beds, was almost as far advanced as it is at the present day.

A continuous belt of Cretaceous deposits appears for the first time in the east between the Wartha and Pilica, enters the basin of Trzebinia near Cracow, and finally reaches the Vistula; the Cretaceous formation, like the Trias, is denuded away, opposite the Carpathians, and on the other side of the Vistula I know of only obscure traces of it, at least in the neighbourhood of Cracow. East of Cracow, however, it covers the plain far and wide.

Eocene beds are unknown in the whole foreland of the Carpathians; but many isolated patches of deposits formed during a Miocene marine transgression occur on the coal-fields; the sediments of this age attain a great thickness on the border of the mountains and form great folds in this region, as I have already mentioned, which have been driven forwards by the Carpathians.—

We have now reached those beds which are directly involved in the movements of the Carpathians. Generally speaking we have arrived at the following conclusions:—

The Archaean rocks of the Sudetes extend southwards to the great fault of Brünn without any deviation; this is also true of the lower and middle Devonian zones. To the south of Weisskirchen the outer border of the Culm zone comes into contact with the outer border of the Carpathians; they are pressed one against the other; *all the other zones of the Sudetes as far as the plain of Poland—Carboniferous, Trias, Jurassic, and Cretaceous —dip from the north beneath the Carpathians.*

The formations which have passed this line of contact, viz. the Archaean, Devonian, and Culm, are suddenly cut off from the Bohemian mass by the fault of Brünn, and the continuation of the outer zones of the Sudetes must be sought beneath the plain of Moravia.

If we would read aright the structure of the Carpathians, we must consequently not lose sight of the fact that, notwithstanding the regular course of its folds, this mountain chain rests, at least in part, *on two other very different fragments of the earth's crust, namely, in the east on the Russian Platform, and in the west on the south-eastern part of the easterly inclined Sudetes.*

### C. *The Sunken Area of Franconia and Swabia.*

A long belt of Rothliegende coming from the south foot of the Riesengebirge marks the true border of the Bohemian mass. In the neighbourhood of Brünn the strata dip steeply to the east towards the fault; at one point, near Rossitz, south of Brünn, a little patch of upper Carboniferous, containing workable coal-seams, appears between the Archaean substratum and the Rothliegende, and very far to the south, near Zöbing,

not far from Krems, a patch of Rothliegende is preserved on the outer side of the fault.

As far as Brünn, the Sudetes lie between the mass of Bohemia and the Carpathians; beyond, the prospect sweeps freely across the plain from the flanks of the Mannharts mountains, which form the border of the Bohemian mass, to the border of the Flysch zone, which here, however, is interrupted by in-sinking.

On the summit of the Bohemian mass only Archaean rocks are to be seen for a great distance, but the out-cropping beds of Rothliegende, rising like notes of interrogation along the marginal fault, show that they must once have been continued over the whole land. In the north their extension is well known, but in the south, also, an isolated patch, near Budweiss, lies in the midst of the chief region of Archaean rocks [1].

In Saxony an extensive denudation of the Coal-measures has been pointed out, which must have occurred before the deposition of the transgressive Rothliegende [2]. If, however, we turn to the western, that is the Bavarian margin of the great mass, we find here also, as Gümbel has pointed out, a fracture which traverses the Fichtelgebirge, and by its continuation the Thüringerwald, at right angles to the strike of the beds. Along this fracture the same belt of steeply inclined Rothliegende projects, and with it the same isolated patches of Coal-measures as we have encountered on the eastern side near Rossitz.

The descriptions of the outcrops of Stockheim and Erbendorf, as well as of the whole, though fragmentary, belt of Rothliegende on the border of the ancient mountains of the Thüringerwald, as far down as Walhalla near Regensburg (the latter itself being built on Rothliegende), show the most striking correspondence with the eastern fault-line, which runs through Brünn, Rossitz, and Zöbing, at the southern foot of the Riesengebirge [3].

The structure of the country which lies on the other side of this western margin of the Bohemian mass as far as the Schwarzwald is peculiar. The whole triangular sheet of Trias and Jurassic formations—bounded on the east by the Thüringerwald, the Frankenwald, the end of the Fichtelgebirge, and the Bavarian forest, on the west by the Odenwald and the Schwarzwald, and on the south, between Schaffhausen

[1] D. Stur, Vorläufige Notiz über die dyadische Flora der Anthracit-Lagerstätten bei Budweis in Böhmen; Verhandl. geol. Reichsanst., 1872, pp. 165–168.

[2] H. Credner, Die geol. Landesuntersuchung des Königreichs Sachsen, 8vo, 1881, p. 9 (from the Mitth. des Vereins für Erdkunde in Leipzig, 1880).

[3] Gümbel, Die Geogn. Verhältnisse der fränkischen Alb (from 'Bavaria'), 8vo, 1864, p. 14; Geogn. Beschreibung des Königreichs Baiern, II, p. 656 et seq., III, p. 555 et seq., et passim. The appearance of Zechstein in the northern part of this region does not really alter the case. F. Beyschlag, Geogn. Skizze der Umgegend von Crock im Thüringerwald, Zeitschr. für ges. Naturw., Halle, 1882, Bd. 55, represents on pl. vii one of these patches of Rothliegende with the marginal faults; here the coal-beds are Permian.

and Regensburg, by a great fault, *the fault of the Danube*—resembles the broken sheet of ice left on a frozen pond after it has been drained. From the ancient granite and gneiss rocks, in the east and west, the Trias and Jurassic sink downwards in steps; before we reach the great transverse fault of the Danube circular pieces subside in the middle of the Jurassic formation, and one of these produces the wonderful Ries caldron, near Nördlingen. On the other side of the Ries caldron the whole of the diversified series of the Swabian Jurassic, together with the underlying Trias, are thrown down along the Danube fault, and their prolongation is to be found beneath the plain, which is bounded on the south by the Alps.

The fault of the Danube has long been recognized as the edge of a great sunken area, and the Ries caldron as the result of collapse, but these are only parts of a single great system of subsidence, extending to the Vogelsberg and the Thüringerwald, as is clearly shown by a series of observations on the faults which accompany the foot of the ancient masses on the east and west. I will only cite a few of the more recent accounts, beginning in the north-east on the border of the Thüringerwald.

In 1855 H. Credner described in detail the faults, running north-east and south-west, which traverse the country on both sides of the Thüringerwald; those of the south-western slope, which are of particular significance for us, have been recently examined by Bücking and Frantzen, whose descriptions of some of them may be regarded as monographs [1].

These works refer chiefly to the district in the Archaean core of the Thüringerwald, which is also bordered by a fault, and extends from the north of Schmalkalden as far as Meiningen. The authors in most praiseworthy fashion examine in detail the movement of each orographic block. It is evident that some of the faults are accompanied by curvature and dragging out of the beds, others not, and although the step-like downthrow is on the whole clear, yet it is occasionally interrupted by faults in which not the southern but the northern side is thrown down, and also by trough formation, that is, by the subsidence of long strips of country between two faults. In the fault which Bücking has described in greatest detail, namely, that between Möckers and Benshausen, the north-western half is thrown down on the north side with a change of level amounting to 370–450 meters, while towards the south-east there is a short interruption in connexion with a transverse fracture, and then for the remainder of its course the downthrow is on the south side.

Here, then, in the middle of the course of the fault there exists, as it were,

[1] H. Bücking, Gebirgsstörungen und Erosionserscheinungen südwestlich vom Thüringerwalde, Jahrb. der k. preuss. geol. Landesanst. und Bergakad. zu Berlin für 1880, 1881, pp. 60–105, pl. ii, iii; W. Frantzen, Die Störungen in der Umgegend des grossen Dollmars bei Meiningen, op. cit., pp. 106–136, pl. iv, v.

a neutral point, and on each side of this movement has taken place in opposite directions; it is the same phenomenon as that we have already pointed out along the great Sevier line in Utah (p. 131); occurrences of this kind testify to the passivity of the sinking mass.

Further to the south the relations become simpler. Gümbel found that on the outer margin of the Neuwald and Fichtelgebirge the Mesozoic strata are always upturned, occasionally even inverted, but within a short distance of the older formations they assume an approximately horizontal position. At the same time four long lines of disturbance are visible, almost parallel to the margin of the mass, which run side by side at nearly equal intervals of about eight kilometers from each other; these may be followed to the south-east up to the western margin of the Franconian Jura, and they extend in part even as far as the valley of the Danube.

These four principal 'splits' are accompanied by dislocation, up-tilting, and crushing, but not by folding. Gümbel points out that their parallelism with one another and with the margin of the mass suggests a common origin: he gives them special names and represents them on the sheets of the geological map of Bavaria, over the district extending from Coburg to beyond Thurnau[1].

We will now leave the Hercynian borderland, with its south-easterly striking dislocations, and travel northwards over the Trias region: then after passing, near Kissingen, the intersection of some great faults striking to the south-east with others striking to the south-west[2], we will make our way to the Odenwald.

Here again, as on both sides of the Bohemian mass, we find an Archaean core surrounded by a girdle of steeply-dipping Rothliegende; the isolated patches of Carboniferous which are found in that region have here, however, been sought in vain. In the neighbouring Mesozoic area parallel faults similar to those described above occur. Benecke and Cohen have given a general account of them, so far as they affect the southern border of the Odenwald[3].

According to the facts presented by these writers three systems of faults may be distinguished in this region: first, those which strike to the north-north-east and occur in the neighbourhood of the Rhine valley; secondly, such as are directed to the north-east and correspond to the outer border of the Odenwald; and, finally, a subordinate group of faults, running to the north-west and crossing the second group at right angles.

[1] Gümbel, Geogn. Beschreibung Baierns, II, p. 592. They are the Culmbach, Weismain, Lichtenfels, and Staffelstein fissures. The author promises much more detailed accounts of these remarkable disturbances.

[2] Gümbel, Geol. Rundschau von Kissingen (from the work 'Bad Kissingen' by Sotier), pp. 13–16.

[3] E. W. Benecke and E. Cohen, Geogn. Beschreibung der Umgegend von Heidelberg, 8vo, 1881, in particular pp. 595 et seq.

The first group has caused the subsidence of the Rhine valley; it makes itself evident chiefly on the eastern border of the Vosges, of the Hardtwald, and no doubt of the Taunus, as well as on the western border of the Schwarzwald and the Odenwald. This is the group of the *Rhine faults*. The second group corresponds to the boundaries of the great Swabian-Franconian sunken area, and the third we may consider as the radial fissures of this area.

To the south of Heidelberg, where the Archaean rocks of the Odenwald are no longer visible and the Trias reaches the edge of the Rhine valley, the faults of the Odenwald, which form the second group, meet the Rhine faults; and here lies the sunken Jurassic area of Langenbrücken, already recognized as such in 1859 by Deffner and Fraas[1].

At this point, close on the edge of the Rhine valley, an Odenwald fault, thrown down on the northern side, is cut by a Rhine fault; the downthrow increases towards the point of intersection, and consequently in the acute angle formed by the two faults there lies an isolated wedge of Jurassic preserved from destruction in the midst of the Trias region, one of the many signs of a once much wider distribution of these deposits.

As in the case of the depression of Langenbrücken, so in that also of the Hilsbach fault, described by Benecke and Cohen. It is the side nearest to the Odenwald, that is, the north-western, which is thrown down, and the more completely known faults of the south-eastern slopes of the Odenwald also have sunk on the northern side, or in the opposite direction to that of the great majority of the other faults in the Franconian-Swabian area of subsidence.

In the Schwarzwald the case is different. Here most exact and remarkable observations have been made by Fraas along the railway line. The Schwarzwald railway from Zuffenhausen, not far from Stuttgart, to Calw exposes a difference of level between the different subdivisions of the Trias amounting to from 350–450 meters, and this is not due to original conditions of deposition, but to eight larger faults and numerous smaller ones, in all of which the eastern side is thrown down relatively to the western or that lying nearer the Schwarzwald; at the same time the inclination of the beds is not necessarily, however, directed to the east. '*The present configuration of the country*,' says Fraas, '*thus appears to be the result of step-like subsidences of the strata, which took place between the Schwarzwald and the Neckar*. In consequence of the in-sinking the tabular mass of strata broke

[1] G. Deffner and O. Fraas, Die Juraversenkung bei Langenbrücken (from the N. Jahrb. für Mineral., &c.), 8vo, Stuttgart, 1859. According to the explicit statements of Benecke and Cohen the Rhine and Odenwald fissures are here separated; Knop and Jordan consider the Odenwald fissure as a continuation of the Rhine fissure running from the south to Langenbrücken: Das rhein.-schwäb. Erdbeben vom 24. Januar 1880, Verhandl. des naturwiss. Vereins zu Karlsruhe, 1880.

into a thousand pieces, which inclined themselves simply in whatever direction space permitted [1].'

Here also, transverse faults, perpendicular to the longitudinal faults, occur. It will be seen that both change their direction as they proceed from the Schwarzwald towards Stuttgart, in such a way that in the Schwarzwald district proper the two directions are to one and seven o'clock, but near Stuttgart, owing to gradual deviation, they are three and nine o'clock; that is to say, the direction of the main longitudinal faults in the Schwarzwald is north to south, but towards Stuttgart it becomes north-east to south-west, while the direction of the transverse faults passes simultaneously from east and west to north-west and south-east.

The railway from Rottweil to Villingen also shows the downthrow of the strata by at least seven step faults; the younger formations are depressed relatively to the older, and, according to the words of the same observer, 'we can no longer speak of the stratified deposits of Swabia as having been deposited against those of the Schwarzwald [2].'

The same system of faults surrounds the Schwarzwald on the south; their existence has been proved by borings in the Coal-measures, and even near Zeiningen, not far from Rheinfelden, a fault striking from the east-south-east meets another which runs to the south-west [3]. In the same way the table-Jura is broken up and fallen in, as though the folded Jura had been driven from the south over a stratified platform in course of breaking down (p. 113, Fig. 10).

All around the Franconian-Swabian sunken area, on the borders of the Schwarzwald, the Odenwald, and beyond, as on those of the Thüringerwald and the Bavarian Forest, the separation of the Mesozoic blocks from the ancient masses is completed by faults, which run more or less parallel to the edge of these masses and are frequently crossed at right angles by transverse faults. Turning to the centre of this region, we meet here also with numerous and unambiguous indications of subsidence. Certain parts of the explanatory text accompanying the detailed geological maps of Württemberg contain a whole store of similar observations, which might furnish the groundwork for a map embracing the fault system of the whole sunken area. Fraas has lately published a brief survey of the most important lines of dislocation [4]. The independence of

[1] O. Fraas, Geol. Profil der Schwarzwaldbahn von Zuffenhausen nach Calw; Württemb. Jahresh., 1876, XXXII, p. 128.

[2] The same, Vorlage der Eisenbahnprofile Bietigheim-Bruchsal und Rottweil-Villingen; op. cit., 1872, XXVIII, p. 66.

[3] A. R. Ausfeld, Geol. Skizze der Gegend von Rheinfelden, Mittheil. Aargauer Naturf. Ges., 1882, III, pp. 83–102; F. Mühlberg, Sammelprofil der Bohrungen, id. loc., with plate.

[4] O. Fraas, Geogn. Beschreibung von Württemberg, Baden und Hohenzollern, 8vo, 1882, pp. xx–xxvi. A number of important facts have been collected by C. Regelmann, Trigonom. Höhenbestimmungen, &c.; Württemb. Jahrb. für Statistik, &c., 1877, V. 'The dip of the strata divides the mass of the Alb into three zones parallel to the strike—

opinion on this point shown by Deffner, one of the collaborators for this special map, will meet with full appreciation and admiration when we mention that more than forty years ago he not only recognized, in opposition to many leading authorities, the true nature of these faults and the universality of the subsidence, but also drew up a map of the faults in the region situated on the middle Neckar to the south of Stuttgart. In this remarkable work he distinguished peripheral and radial faults under these very names; showed the crescentic curvature of the peripheral lines as they passed from a direction running north and south to one almost west and east; and finally decisively expressed his conviction that the younger eruptive rocks, which here and there accompany these faults and subsidences, are not the cause but the result of fissures, produced in the solid crust of the earth by other means. Deffner even went so far as to inquire whether some connexion might not be found to exist between this extensive subsidence and the origin of the Alps, 'in such a way, perhaps, that a movement of the fluid nucleus of the earth towards the line of elevation of the central chain of the Alps might result in the subsidence, up to a certain distance, of the neighbouring peripheral region [1].'

Fraas also emphasizes the parallelism of the Danube fault with the margin of the Alps. 'At the same time,' he says, 'as the folds of the Alps arose, the tableland of the Jura split in the same direction [2].'

The outline of the sunken area is distinctly wedge-shaped on the north, the peripheral faults are long and straight and, so far as can be judged from existing observations, intersect each other at acute angles towards the north; they appear to unite in curves as they approach the centre; whether they finally reach the fault of the Danube I am unable to decide. To the north of the fault of the Danube another kind of subsidence occurs in the form of caldron inbreaks. The smallest of these, if it can be placed in this group at all, lies near *Steinheim*, not far from Heidenheim; it is hardly one kilometer in diameter and is filled with Tertiary fresh-water formations. The Ries caldron, in which Nördlingen lies, and that of the Höhgau, are typical examples of this group.

## D. *Ries and Höhgau.*

Of the writings dealing with the structure of the Ries caldron it will

a nearly horizontal outer zone on the north, a gently inclined middle zone, and a southern outer zone with a very strongly marked inclination' (tom. cit., p. 137).

[1] G. Deffner, Die Lagerungsverhältnisse zwischen Schönbuch und Schurwald, Württemb. Jahresh., 1861, XVII, pp. 170–262, pl. iv and v, in particular pp. 256 et seq.; and as a supplement to the description of this district, Fraas, Begleitworte zum Atlasblatt, Stuttgart, 1865; H. Bach, Atlasbl. Boblingen, 1868; Deffner, Atlasbl. Kirchheim, 1872, and others.

[2] O. Fraas, Geogn. Beschreibung von Württemberg, p. xix.

suffice to mention those of Deffner and Fraas for the part which lies in Württemberg, and that of Gümbel for the Bavarian part[1].

The Ries presents much that is instructive in the study of the collapsed area of the Alps, and I shall therefore treat it in some detail. That I am in a position to do so I owe to my friend and master Oscar Fraas, who has had the kindness to guide me to the most important localities and to explain their most important features.

Seen from a height, for example from the summit of the Ipf near Bopfingen, the Ries resembles a broad flat plate. It is a circular plain from 12 to 15 kilometers in diameter, which is drained by streams with a trifling fall through a gorge to the south. Two chains of low hills extend across this in somewhat divergent directions from the south; that on the west runs past Nördlingen towards the Wallerstein, the other on the east past the Spitzberg to the Wenneberg.

Each of these chains consists of two different parts, viz. of an older foundation and a younger crown. The older foundation is composed chiefly of decomposed Archaean rocks, granite or fibrous amphibolite, which has also been termed diorite. Here and there we find, however, intercalated among these Archaean remains, patches of red or blue Keuper marl, of lower Lias, and of clay with *Amaltheus margaritatus*, or certain stages of the middle Jurassic. At the Wenneberg a small dyke of recent eruptive rock also crops out. These are the visible summits of sunken fragments, the lower parts of which are covered by the plain. The crown of these ranges is formed of Tertiary fresh-water formations, consisting sometimes of Littorinella limestone, sometimes of a breccia cemented together by fresh-water limestone, but in the most typical cases of coarsely laminated travertine, built up by gas-charged springs in the middle of the Tertiary lake. The travertine forms, for instance, the precipitous and remarkable mountain of Wallerstein, which stands on a broad granite ridge, a surviving fragment of a once much greater bell-shaped structure. No doubt it and its companions, the Spitzberg and others, originally presented no small resemblance to those bell-shaped formations which have given its name to Pyramid Lake in West Nevada[2].

[1] G. Deffner and O. Fraas, Begleitworte zur geogn. Specialkarte von Württemberg, Altasblätter Bopfingen und Ellenberg, 4to, 1877; also Fraas, Geogn. Beschreibung von Württemberg, pp. xxxi and 161; and with regard to volcanic phenomena in connexion with the structure, Gümbel, Ueber den Riesvulcan und über vulcanische Erscheinungen im Rieskessel, Sitzungsber. k. Akad. Wiss. München, 1870, I, pp. 153–200; G. Deffner, Die Granite in den vulcanischen Tuffen der schwäb. Alb, Württemb. Jahresh., 1873, XXIX, pp. 121 et seq., and many other works. v. Dechen also regards the Ries as a subsidence, and the primitive formations in the Ries as part of an old continent: Ueber auffallende Lagerungsverhältnisse, Verhandl. naturhist. Vereins Rheinl. Westph., Sitzungsber., 1880, XXXVII, p. 37. For thrusting, in particular, see G. Deffner, Der Buchberg bei Bopfingen; Württemb. Jahresh., 1870, XXVI, pp. 95–142, 3 pl.

[2] C. King, Rep. on the Geol. Explor. of the 40th Parallel, 4to, 1878, I, p. 515, pl. xxiii.

In these deposits of travertine Fraas has discovered an unexpected wealth of organic remains, bones, feathers, birds' eggs, and fragments of small mammals, thereby proving that these deposits in the middle of the Tertiary lake were nesting-places of numerous pelicans and ducks.

The fragments of sunken formations outside these two chains of hills are, as we have said, covered up by the plain. Here and there are some patches of volcanic tuff, but the soil of the plain itself is formed of Tertiary beds containing brown coal, and of loam, which have been sunk through in places for 200 feet without reaching their base.

If now we examine the margin of the plain we shall find great difficulty in determining the tectonic limit of the subsidence. Round about the edge of the caldron, and for a considerable distance from it, all the strata have collapsed and broken up. The border of the subsidence is concealed over large areas by deposits of travertine or by a breccia of Tertiary age. Sometimes the granite crops up from beneath this cover, sometimes there jut up along the edge reefs of upper Jurassic limestone, the strata of which stand on end, fallen in, and sometimes so completely shattered by pressure that a slight blow is sufficient to cause the limestone to fall into innumerable angular fragments.

Outside the plain of the Ries and in isolated troughs between these shattered strata the most remarkable eruptive centres of the border region occur. I have visited those at Heerhof, south of Kirchheim, and at the ancient Bürg (Dombruch) west of Edernheim.

At the Heerhof a broad rounded hill may be seen between the Jurassic mountains, which is composed of coarsely stratified masses of ash and lapilli. The somewhat divergent dip in the two neighbouring quarries probably indicates the site of the centre of eruption. Neither dykes nor flows are to be seen, but in the ash lie numerous fragments of scoria, ear-shaped in form or spirally rolled, and sometimes drawn out behind into a long tail like a comet. These were once gyrating drops of lava, which flattened out on reaching the ground and then solidified. They leave no room for doubt as to the immediate neighbourhood of the vent.

There are similar volcanic bombs at the ancient Bürg; many fragments of Archaean rocks lie in the ash, and a great block of Jurassic breccia is enclosed in it.

Many years ago Gümbel inferred from the occurrence of isolated bombs in the Ries, that true eruptive centres must be present in this region. The absence of dykes and flows at these points recalls the variable eruptive centres of the Phlegraean Fields, as well as Monte Nuovo and

The 'rough bothryoidal surface, which has the appearance of being made up of large mushroom-like forms overlapping each other like roof tiles,' is exactly similar to that of the deposits of the Wallerstein.

similar mountains, which were formed by a single eruption, but did not become permanent eruptive centres.—

The question whether the Ries caldron is to be regarded as an independent circular collapse of the earth's crust, as the circular outline of the plain suggests, or whether the subsidence took place between long straight faults, extending beyond the region of the Ries, is difficult to decide. Deffner and Fraas recognized a number of rectilinear faults in the shattered deposits of the border regions to which they gave names, such as the Sigart-Hürnheim axis, the Zipplingen axis, &c. In addition a number of small isolated 'sporads of dislocation' were distinguished in this area, among which the small inbreak of Herdtfeldhausen is the most remarkable.

The most important independent fault is certainly the Sigart-Hürnheim line, also known as the Utzmemmingen line. It strikes from north-west to south-east, approaches the south-western part of the Ries region at a tangent, and is accompanied by small parallel faults. On the south-western border of the Ries a succession of strata may be seen, extending from the base of the middle Jurassic to the upper Jurassic. This, four times cut by faults, is as many times repeated; it is inclined throughout its whole thickness away from the Ries district, in a south-south-west direction, towards the Utzmemmingen fault-line.

The trifling dimensions of some of the sunken areas, e.g. that near Herdtfeldhausen, the circular outline of the little subsidence of Steinheim, the excessive fragmentation of the Jurassic limestone on the edge of the Ries, together with the occurrence of other areas of depression of greater extent, but with less vertical downthrow, in the neighbourhood of the Ries, as near Neresheim and between Ellenburg and Bopfingen, finally the association of volcanic phenomena near Urach: these and similar facts have produced in my mind the impression that triangular or trapezoidal segments have been determined by the intersection of several fractures, and that as the subsidence advanced by step faults the action of pressure on the corners converted the triangles into hexagons, the quadrangles into octagons, till by the more or less regular multiplication of the sides of the polygons the inner area of subsidence attained its circular outline, which is now surrounded by a margin of broken-up segments.

Sunken areas, distinct from one another, large and small, deep or shallow, accompanied or not by volcanic eruptions, might, in this way, have originated here. The sinking-in, however, is, as in so many areas of depression, succeeded by another process, which here indeed seems to have followed much later, namely, the thrusting of some of the segments over others. Fraas has recognized one such overthrust over a polished and striated surface of the upper Jurassic, near the tunnel of Lauchheim, west of the Ries; and Deffner has since established in detail the overthrusting of a great mass of middle and some upper Jurassic still nearer the Ries, at the Buchberg near

Bopfingen. Here, too, the polished overthrust surface is formed on the upper Jurassic stage $\gamma$; the direction of the movement was from east-north-east to west-south-west, and it has been shown that the grains of quartz which scour this surface are not derived from the overthrust middle Jurassic, but from a bed of sand, which is probably more recent than the Tertiary.—

Far away from the Ries, at the south-western termination of the Swabian Alps and already facing the lofty chains of Switerland, lies the sunken area of the *Höhgau.* Great volcanic masses rise within it, and at one time the ash cones of these volcanos probably covered its whole surface. In outline it is more square than circular and its longest diameter measures about 18 kilometers. The sunken area is not closed, but open on the south towards the Lake of Constance. Level bog-land sharply defines the fracture on the inner side for long distances. In the middle of the depression stands a broad group of closely connected hills formed of fresh-water Molasse, volcanic tuff, and heaps of erratic material; from these the volcanic summits rise[1].

The western eruptive masses, of which the Hohenstoffel is one, are basaltic; the eastern mountains, the Hohentwiel, Hohenkrähen, and Magdeberg, are formed of phonolite. Fraas has expressed the opinion that masses so precipitous as the Twiel must have consolidated within a covering of ash; indeed, considerable portions of the old ash cone may still be observed, especially on its western side, and the sharp preservation of the outlines of the most delicate six-sided mica flakes shows that the ash has not been washed about by water since its accumulation.

The panorama from the Hohentwiel I consider one of the most instructive, as regards the relationship of different mountain systems to one another, I have ever seen. On three sides the mountain is surrounded by the down-sunken area of Jurassic strata, and only its accompanying volcanic masses which intervene hinder a full view over the broken edge. To the south a flat country stretches far away, and on the shores of the Untersee may be seen the hills of Oeningen, composed of fresh-water Molasse, with interspersed ash from the Höhgau, which fell when that rich flora, so clearly made known to us by the labours of Heer, was in full existence. Beyond the Untersee, behind the dark outlines of the city of Constance and the shining surface of the lake, tower the mighty folds of the Säntis, like an overwhelming breaker rising from the solid earth itself.

## E. *The Horsts.*

We will descend from the Schwarzwald into the valley of the Rhine. Here many years ago Élie de Beaumont pointed out the existence of a number of faults, which strike fairly parallel to one another towards the

[1] O. Fraas, Geogr. Karte von Württemberg, Bl. Hohentwiel, with text, 1879.

north-north-east, and divide into longitudinal strips the two slopes of the Schwarzwald and the Vosges which face the Rhine. According to de Beaumont there first occurred an upward dome-like swelling of the whole country, including the Vosges and the Schwarzwald, and this was followed by a step-like subsidence on both sides which formed the present Rhine valley. The fact that on the higher parts of the Vosges only Vosges sandstone is to be found, the Bunter sandstone first appearing on the lower steps of the mountains, and again, that owing to the inclined position of the sunken strips the Bunter is in apparent discordance with the Vosges sandstone, which lies above, led Élie de Beaumont to the conclusion that the Vosges sandstone had been converted into dry land before the deposition of the Bunter, which was laid down upon it at the foot of the mountains [1].

This error was rectified by Bleicher in 1870. That the Vosges sandstone is seldom covered by the Bunter, Bleicher ascribes solely to the excessive denudation of the younger beds; he maintains besides that the Vosges sandstone was once covered not only by the Bunter, but by the whole of the Trias and Jurassic formations, which extended from Lorraine over this whole region as far as Württemberg [2].

De Beaumont's views have given rise to a lively discussion; the discordance between the Vosges sandstone and the Bunter has found champions even up to the present time, especially in Baden, but it seems to me that since Benecke's representation of the true state of things, this question must be considered as decided against de Beaumont [3].

To the great French investigator the honour is none the less due of having been the first to recognize the position of the most important fault lines, and the chief features in the peculiar structure of the Rhine valley.

If now we cross the Vosges we shall find, not only on their western slopes, but in many parts bordering on the Central Plateau of France, particularly around the Morvan, which forms its north-eastern foot-hills, a great system of faults similar to those which we have just described in Bavaria and Württemberg. Recent publications by French authors furnish many examples of these faults. There can thus be no doubt that around the mountains mentioned above, on the borders of the Bavarian and Thuringian forest, around the Schwarzwald and the Vosges, about the Odenwald, and far to the west around a great part of the Central Plateau of France,

[1] Élie de Beaumont, Explic. de la carte géol. de la France, 1841, I, pp. 267–437.

[2] G. Bleicher, Essai de géol. comparée des Pyrénées, du Plateau Central et des Vosges; Thèse prés. à la Fac. des Sciences de Strasbourg, 8vo, Colmar, 1870, p. 71 et seq.

[3] E. W. Benecke, Ueber die Trias in Elsass-Lothringen und Luxemburg, Abhandl. zur geol. Specialkarte von Elsass-Lothringen, 1877, I, p. 794 et seq., and Abriss der Geol. von Elsass-Lothringen, 8vo, Strasburg, 1878, p. 110 et seq. Sandberger and Platz may be mentioned as representing Beaumont's view, Lepsius and Laspeyres for the opposite theory.

the sheets of Mesozoic deposits have sunk down, and out of *this general subsidence these mountains rise as horsts*, themselves mere fragments of ancient folded chains, having a strike which is often discordant to their outline, and revealing Archaean rocks only where these have been exposed by denudation. We must picture a common and continuous foundation of Palaeozoic and Archaean formations, extending from the Central Plateau to the Böhmerwald; on this were spread out the strata of the Trias and Jurassic oceans. No relics of the shores of these seas are anywhere preserved in this vast area; we do not even know whether their waters covered nearly the whole or only a small part of the two chief plateaus, viz. that of Bohemia and that of Central France, but there is no evidence that any important barrier separated them in the interval between the two great masses. This common foundation has now sunken inwards, bearing with it all its Mesozoic beds, and the horsts which remain standing between the various sunken areas owe their height, not to independent elevation, but to this general subsidence of the surrounding region. To obtain an idea of the true extent of these downward movements of the earth's crust, and of the subsequent denudation, we should have to pile up on the Vosges, on the Schwarzwald, and their northern prolongations the whole thickness of the Trias and Jurassic systems.

There can be no doubt that the whole of the Bohemian mass was also subjected to extensive denudation before the deposition of the Coal-measures; a second period of denudation occurred before the deposition of the Rothliegende; and again, a very extensive denudation preceded the Cenomanian stage. The case is similar on the Central Plateau of France, and on that extensive mass which forms a great part of the Iberian peninsula and which we shall discuss later under the name of the Iberian Meseta. At present we can formulate no theory as to the connexion of these events in time. On the other hand the chief features of their continuity in space are already established. The continuation of the Coal-measures of the Morvan is already sought for in those of Rochebrune on the southern border of the Vosges. *The Mesozoic deposits sink into the interior, and in the horsts an older Europe stands disclosed.*

The hypothesis that the margins of these horsts represent the ancient shores of Mesozoic seas is quite untenable; this is clearly demonstrated by the distribution of some important stages, such as the Muschelkalk, which surrounds the mountains of the Rhine, and terminates within the Paris basin. Equally erroneous, however, would be the supposition that these masses are everywhere limited by continuous peripheral fractures. Fissures of various kinds, in many instances true radial clefts, are continued from the subsided Mesozoic strata into the ancient gneiss or granite masses, where, as a rule, they are distinguished by veins of quartz or barytes.

The outlines of the horsts are themselves influenced by fissures of this

kind. The manner in which, according to the investigations of Grebe, the Mesozoic platforms subside on a network of faults striking to the north-east or north-north-east on both sides of the Hochwald near Trèves, thus leaving it projecting like a spur into the subsided basin of Paris, is an excellent example of the difficulty in establishing a definite rule as to the mode of limitation of sunken areas [1].

The faults which, according to Michael Lévy and Vélain, surround the northern and western Morvan 'in tangents,' and from which the stratified formations descend in steps, are sometimes accompanied by quartz-veins, sometimes by veins of red hornstone, fluorspar, and barytes. Fragments of Lias lie in the faults on the summit of the Morvan [2].

Generally speaking the characteristic features of subsidence and denudation are much more clearly displayed around the margin of the Central Plateau of France than in South Germany [3].

In the Vosges Élie de Beaumont had already recognized and discussed in detail the connexion between the faults, the metalliferous veins, and the great dykes of quartz which sometimes rise several hundred feet above the surrounding country [4]. In addition to the veins in the granite, which strike in the same direction as the Rhine fissures, we may refer here to the great quartz-vein of the Val d'Ajol in the south-east, which strikes E. 35° N. and passes near the hot springs of Plombières.

The conduits of the springs intersect veins which bear quartz, fluorspar, barytes, and pyrites, and, as Daubrée's masterly investigations have made known, the water of the springs has deposited fluorspar in the Roman brickwork [5].

[1] H. Grebe, Ueber das Ober-Rothliegende, die Trias, &c., in der Trier'schen Gegend, Jahrb. k. preuss. geol. Landesanst. für 1881, p. 471 et seq., pl. xii; for the continuation towards Metz, see G. Steinmann, Geol. Führer der Umgegend von Metz, Jahresber. des Vereines für Erdkunde zu Metz, 1882, IV, p. 10; also Benecke's well-founded remarks in the Neues Jahrb. für Mineral., &c., 1880, I, p. 222.

[2] M. Lévy et C. Vélain, Sur les failles du revers occidental du Morvan; Bull. Soc. Géol. de Fr., 1877, 3e sér., V, pp. 350-365. The faults of the east border of the Morvan appear to extend far into its interior; they are injected with basalt near Alligny to the south of Saulieu: tom. cit., p. 562 et seq.; Beaumont, Explic. géol., II, pp. 207, 273, et passim; also Gruner, Essai sur une classific. des principaux filons du Plateau Central de la France, Ann. des Sciences de la Soc. imp. de Lyon, 1856, 2e sér., VIII, p. 202 et seq.

[3] Near Thiviers, in the Dordogne, along a great marginal cleft on the south-western border of the plateau, the Belemnites of the oolite are converted into barytes (Harlé, Note sur les form. jurass. et la position des dépôts manganésifères dans la Dordogne; Bull. Soc. Géol. de Fr., 1864, 2e sér., XII, p. 33 et seq.); on the south-eastern border the faults in the Coirons were already completely levelled by abrasion, when they were covered by basalt (Torcapel, op. cit., 1882, 3e sér., X, pp. 409, 412).

[4] Élie de Beaumont, Explic. de la carte géol. de la France, II, p. 417 et seq.

[5] Daubrée, Mém. sur la relation des sources thermales de Plombières avec les filons métallifères; Ann. des Mines, XIII, 1858. We will only briefly refer to the springs of Kreuznach and of Dürckheim on the Hardt, which lie on the Rhine faults; the oldest known deposits formed by the springs are here too composed of quartz: Laspeyres,

Similar veins are not wanting on the western margin of the great sunken area of Franconia and Swabia; here they generally take the direction of radial fissures.

The barytes vein of Schriesheim, which strikes east-south-east, described by Benecke and Cohen, may be mentioned first[1].

A number of veins striking to the south-east occur in the broad belt of Bunter sandstone which is continued southwards from Pforzheim into the Rhine valley, and these are succeeded further to the south by the veins of Neu-Bulach, with similar strike; they are filled chiefly with barytes, and are continued as faults into the Trias. The Hochsträss fault described by Bach[2] is an example; this also strikes to the south-east and connects these veins with the network of fractures in the Trias of Swabia.

Further to the south this connexion is still more striking. Near Freudenstadt, in the duchy of Württemberg, a large mass of Muschelkalk is sunk into the Bunter sandstone and, as Paulus has shown, between parallel faults, which are about 8 kilometers apart and strike to the south-east. Here we are already in the region of Deffner's radial fissures. Both faults are indicated by fissures, which are filled with barytes for great distances, and deeper down by quartz, carrying copper and a little galena. Between these two principal veins appears a group of smaller ones, also parallel and filled with barytes[3].

These veins, which, as we have said, correspond to the lines of fracture in the Swabian Trias, are only part of a much larger group which attain their greatest development near Rippoldsau and Wittichen in the valley of the Kinzig: they show that the fracture along which the Trias is faulted extends far into the Archaean core of the Schwarzwald. The connexion of the faults in these two regions has been recognized by all observers, in particular by F. Sandberger, who has studied the veins of the Kinzig valley in great detail[4].

Kreuznach und Dürckheim a. d. Hardt, Zeitschr. deutsch geol. Ges., 1867, XIX, pp. 803-922, pl. xii, and 1868, XX, pp. 153-204, particularly p. 188 and pp. 198, 199. In the same way the Haus-Baden, on the western declivity of the Schwarzwald, close to the thermal spring of Badenweiler, lies on a Rhine fault: Sandberger, Geol. Beschreibung der Umgegend von Badenweiler, Beitr. inn. Stat., 1858, VII, pp. 14, 15. Daub, in 1851, thought he could trace the original continuity of these fragments through the whole length of the Schwarzwald, and pointed out their parallelism with the faults of the Vosges described by Beaumont: Daub, Die Feldsteinporphyre und die Erzgänge des Münsterthales bei Staufen, Neues Jahrb. für Mineral., &c., 1851, pp. 1-23.

[1] E. W. Benecke and E. Cohen, Umgebung von Heidelberg, p. 178 et seq.

[2] H. Bach, Begleitworte zur geol. Karte von Württemberg, Atlasbl. Calw, 1869, p. 18.

[3] E. Paulus, Begleitworte zur geogn. Specialkarte von Württemberg, Atlasbl. Freudenstadt, 4to, 1866, p. 13.

[4] Sandberger, Geol. Beschreibung der Umgebungen von Renchbäder, Beitr. zur Statistik der inn. Verwalt. des Grossherzogthums Baden, Heft XVI, 1863; Vogelgesang, Geogn. bergmänn. Beschreibung des Kinzigthaler Bergbaues, op. cit. Heft XXI, 4to, 1865, and

On the slopes of the Bavarian Forest these phenomena occur on a much larger scale and present remarkable modifications. In order, however, to show more clearly the structure of the margin of this mass, I will preface this explanation by a few words on a similar district, the north of Scotland.

Archaean and Silurian rocks, thrown mostly into parallel folds, and Old Red sandstone build up this wild mountain land. For a long time small isolated patches of Jurassic beds, such as the coal-bearing deposit of Brora, have been well known, but it has only recently been shown by Judd that this whole country, with its present diversified surface, was once concealed beneath a covering of Trias and Jurassic and by beds of middle and upper Cretaceous age. The fragmentary remains of this covering have been preserved to the present day, partly beneath fragments of Tertiary lava flows, as in the west of the country, and partly by mighty faults. Such faults have determined the course of the coasts of Sutherland and Ross. Along these fractures the land has sunk down beneath the Dornoch and Moray Firths. A narrow and much interrupted belt of Trias and Jurassic deposits is visible along the faults close to the edge of the sea. In Sutherland the fault for a certain distance becomes stepped, and a band of middle Devonian appears on its upper step, a band of upper Oolite on the one below. Above these steps the granite is exposed. All the higher land is formed of lower Silurian and Old Red sandstone, while beneath the sea, which is of no great depth, Mesozoic deposits are preserved, perhaps over large areas. The fracture which borders Moray Firth on the west is probably the continuation of that great dislocation which traverses the whole country from sea to sea along the Caledonian Canal [1].

Here, too, the ancient mass appears as a horst; along its jagged borders, at a lower level, lie the Mesozoic deposits. At the foot of the Vosges also a zigzag outline, though on a smaller scale, is to be seen, produced in this case by the penetration of the long Rhine fractures into the river valley. If, however, eastern Bavaria, and especially the basin of the Naab, were to be covered to-day by the sea, then the coast-line of the Bohemian mass would present an outline on the west which would resemble in its main features that of the north-east of Scotland. The bays of Weiden and Schwandorf would correspond to the Dornoch and

particularly F. Sandberger, Untersuchungen über die Erzgänge von Wittichen im bad. Schwarzwalde, Neues Jahrb. für Mineral., &c., 1868, p. 388. Sandberger, in his instructive monograph on the chief vein of Schapbach (Untersuch. über Erzgänge, 1882, I, p. 45), referring to the manner in which these veins are filled, mentions rounded pebbles of Vosges sandstone, which show that barytes veins were formed here before the deposition of the sandstone, but leaves the reader in no doubt that the veins mentioned here are of younger age, and are often continued as ramifications of quartz or barytes in the Bunter sandstone.

[1] J. W. Judd, The Secondary rocks of Scotland; Quart. Journ. Geol. Soc., 1873, 1874, 1878, and in particular 1873, pp. 131–134, pl. vii.

Moray Firth, and just as the great fracture of the Caledonian Canal may be recognized on the western side of the Moray Firth, nearly as far as Tarbet Ness, so we should see here the continuation of a fault many miles long, the line of the Pfahl, issue from the Archaean mountains and form the northern boundary of the 'bay' of Schwandorf, nearly as far as Amberg.

These Archaean mountains are, as we know from the laborious and detailed investigations of Gümbel, folded in the north, especially in the Fichtelgebirge; the folds strike to the north-east, so that this district forms a continuation of the Erzgebirge. In the south, on the other hand, a uniform dip of the strata to the north-east is the rule, so that the oldest members of the series crop out along the Danube, and along the fault to the east of Amberg. In this mountainous country several gigantic outcrops of quartz appear, which I regard as the grandest monuments of linear dislocation known in our continent.

Three of these outcrops are of particular importance. The first has been described by Reuss and Jokely. It begins in the most north-westerly part of Bohemia, north-west of Asch, runs to the south-east, transversely across the mica-schist, gneiss, and granite of the Erzgebirge, that is, the most important zones of rock in the chain, then it cuts across the narrow outcrop of gneiss which accompanies the southern foot of the Erzgebirge near Seeberg, disappears beneath the Tertiary covering of the little depression of Franzensbad and Eger, and reappears immediately on the other side of this in the granite mass of Sandau, and extends through this up to the south of Königswart. The distance between its two ends is about 40 kilometers[1].

This ridge of quartz, which is shown to be quite certainly a vein by the manner in which it crosses the Erzgebirge, has not indeed a strictly rectilinear course, yet deviates so little from a straight line, that the connexion of the two parts separated by the Tertiary area is an obvious inference. At its southern end, as Hochstetter has shown in his Studies of the Böhmerwald, a subsequent disturbance in the structure of the country may be recognized. The first vein of quartz is accompanied at this extremity by smaller veins or branches, and still further to the south-west, as though a horizontal displacement had occurred, there appears, near Hals, north-west of Tachau, the beginning of the second great vein, which Hochstetter was the first to trace, and which he has named the *Bohemian Pfahl*[2].

[1] A. E. Reuss, Die geogn. Verhältnisse des Egerer Bezirkes und des Ascher Gebirgsgebietes in Böhmen, Abhandl. geol. Reichsanst., 1852, I, pp. 30-32; J. Jokely, Zur Kenntniss der geol. Beschaffenheit des Egererkreises in Böhmen, Jahrb. geol. Reichsanst., 1856, VII, pp. 527, 528. These great dykes of quartz are also marked on F. v. Hauer's Geol. map of Austria.

[2] F. v. Hochstetter, Geogn. Studien aus dem Böhmerwalde, IV; Jahrb. geol. Reichsanst., 1855, VI, pp. 767-774, and the diagram, p. 762.

It is extremely probable that this ridge, which, generally speaking, strikes to the south-south-east, was originally continuous with that of Asch. It at first describes a marked curve to the east, then it turns back to a straight direction and crosses the Bavarian frontier near Furth; still further, on the western slopes of the Hohe Bogen, some separate smaller veins are to be seen which mark its southern termination [1].

The distance between the extremities of this ridge is about 55 kilometers. The thickness in some places is 30 meters, at others it appears to increase to from 70–100 meters. For a very long distance the quartz sharply marks the limit between the gneiss and the hornblende-rock; this circumstance and its very considerable thickness probably account for its having been at first regarded as a bed; however, besides the fact that at certain points where the boundary of the hornblende rock forms a bend the quartz does not follow it, but cuts across the bend in a straight line, we find also that towards the south the vein leaves the boundary between the gneiss and hornblende-rock altogether, and passes completely into the latter. It is consequently a true vein, like the northern chain of outcrops which traverses the Erzgebirge, and the fact that for a long distance it marks the boundary of two different rocks only testifies to the extraordinary extent of the dislocation and of the subsequent denudation.

The third outcrop of quartz, the *Pfahl* or Vallum, is the most considerable of all. Wineberger has described it in part; for a complete account we are indebted to Gümbel [2].

The Pfahl, or the *Great Pfahl* as we will call it, to distinguish it from the Bohemian Pfahl, deviates less from the rectilinear than the other series of outcrops. Its direction is N. 58° W., its thickness varies: for the greater part, at least over the northern half, it seems to be from 70 to 115 meters on an average. The Pfahl begins at Kolmberg, south-east of Amberg, and from there for a distance of about 44 kilometers to the south-east it separates the granite from the Trias and middle Jurassic, and then to the west of Cham passes completely into the Archaean region, and continues without deviation in a straight line to the south-east, through Viechtach, Grafenau, and Freyung, as far as the Austrian frontier. The whole length from the Kolmberg to this point is somewhat over 150 kilometers. The distribution of the rocks in upper Austria and the completely coincident course of the upper Mulk valley seem, however, to indicate that the dislocation is continued still further to the south-east. To the north-west, continuing the direction of the Great Pfahl far beyond Amberg, a disturbance occurs in the Mesozoic deposits, accompanied by

[1] Gümbel, Geogn. Karte des Königreichs Baiern, Bl. IX, Cham.

[2] L. Wineberger, Geogn. Beschreibung des bairischen und Neuburger Waldes, 8vo, Passau, 1851, and Gümbel, Geogn. Beschreibung des Königr. Baiern, II, p. 372 et seq., pp. 497, 508, et passim.

a vein of iron ore, which Gümbel assigns to the lowest horizon of the Cretaceous deposits of this district.

The Pfahl also was interpreted as a bed. Gümbel, however, has enumerated all the serious objections which may be urged against this view, above all its extraordinarily long and straight course, such as, we may venture to affirm, is nowhere presented by any ordinary stratified formation in any part of Europe, least of all in Archaean complexes, and again the repetition of certain dominant directions of strike to the north and south of the Pfahl, which, however, do not cause this feature to diverge from its course [1]. If we consider, further, that the direction of the Pfahl is visibly continued by a line of dislocation towards the north-west, that a parallel vein accompanies it between Bodenmais and Kotzing at a distance of from 8 to 8½ kilometers, that the southern marginal fracture of the mountains along the Danube is also nearly parallel to it, and that at present no one doubts that the great quartz outcrops of Bohemia are true veins, then we shall also be forced to admit that the Great Pfahl represents the infilling of a long cleft produced by dislocation.

A number of subordinate quartz veins are present in addition to the great dykes, as, for example, in the granite of Tirschenreuth. Here, too, veins of barytes and galena are found within the region of Mesozoic fractures.

Powerful faults, issuing obliquely from the Archaean mass and penetrating into Bavaria, are characteristic of the fractured margin of this country, and give rise to great zigzags in its outline, which recall those of the east coast of Scotland. In this respect it presents a striking contrast to the uniformity of the eastern margin of the Bohemian mass, which, as we have already seen, continues the marginal fracture of the Sudetes, and forms a sharply defined slope from Brünn to the Danube.

### F. *Jurassic Relics of the Sudetes.*

On the border of the Bohemian mass, which extends along the Danube below Regensburg, very remarkable phenomena make their appearance. The Rothliegende, which we have hitherto found to accompany the border of this mass, now appears for the last time near Donaustauf. It is not to be seen anywhere around the southern border of the mass, and only becomes visible again on the eastern marginal fracture, near Zöbing to the north of Krems. The gneiss begins to extend across the Danube and sinks very gradually in the region to the south of Engelhardtszell, beneath a covering of Tertiary deposits. Already, far to the north-west, we may see in Franconia how different members of the Trias and Lias diminish in thickness and finally disappear. But beyond Regensburg, along the Danube towards Passau, we see what does not occur

[1] Gümbel, tom. cit., p. 377.

elsewhere in the whole district, namely, isolated patches of the upper Jurassic, resting immediately against those outer slopes of the Archaean mountains which look towards the great plain, as, for example, in the neighbourhood of Straubing and of Hofkirchen, and, with a greater extension, to the south of the Danube near Ortenburg, and even nearer still to Passau, though then only visible in isolated exposures beneath a mantle of Tertiary deposits. The middle and upper Cretaceous accompany the Jurassic over the whole of this line.

Let us first consider the disposition of the strata. On the lower course of the Regen, the Jurassic, some Lias and Keuper rest steeply against the granite; south of Regenstauf the strata are inverted, and dip beneath the granite. The last of these fragments, directly contiguous to the principal mass of the Franconian Jura, reaches the Danube between Regensburg and Walhalla, leaning steeply against the granite. The outline of the granite mass forms almost a right angle. The Rothliegende appears for the last time near Donaustauf.

The isolated fragments of the Jurassic formation, which near Straubing are still accompanied by Keuper, have suffered great disturbance; near Voglarn, not far from Ortenburg, there occurs indeed, as we have already said, a synclinal fold directed downwards, the middle of which consists of gneiss, while the limbs are formed of overfolded Jurassic strata, and beneath these dips the Cretaceous which also has been involved in this extraordinary movement (p. 138)[1].

At the same time the composition of the Jurassic series undergoes great changes, which increase as it becomes more remote from Regensburg: the Lias disappears; the middle and upper brown Jura unite to form a single bed containing species which otherwise do not occur together; as, for instance, near Cracow, where a number of forms appear which are common to the middle Jurassic of Cracow. Equally striking is the alteration of the upper Jurassic; the truth of the suggestion made long ago by F. Roemer and Neumayr has been established by the latest work of Ammon and Uhlig, and the Jurassic deposits of Passau have been shown to correspond with the isolated remnants near Brünn, and with the beds of the region of Cracow, and all these deposits were originally continuous[2].

[1] J. G. Egger, Der Jurakalk bei Ortenburg, from the I. Jahresber. des naturhist. Vereines in Passau für 1857, p. 6 et seq.; Gümbel, Geogn. Beschreibung des Königr. Baiern, II, p. 695; L. v. Ammon, Die Jura-Ablagerungen zwischen Regensburg und Passau, Abhandl. des zool.-mineral. Vereins in Regensburg, 1875, X, pp. 94–97.

[2] F. Roemer, Geol. Oberschlesiens, p. 276; M. Neumayr, Die Cephalopodenfauna der Oolithe von Balin bei Krakau, Abhandl. geol. Reichsanst. Wien, 1871, V, pp. 50, 51; Ammon, tom. cit., in particular p. 151; V. Uhlig, Die Jurabildungen in der Umgebung von Brünn, Mojsisovics und Neumayr, Beitr. zur Palaeont. Oesterr.-Ung., 1881, I, pp. 141–145. On the character of the Cretaceous formations, see Carl Gerster, Die Plänerbildungen um

This zone of Jurassic and Cretaceous resting against the Bohemian complex terminates near Passau; but far to the south-south-west, just at that point where a line drawn from Passau towards Salzburg would cut the outermost border of the Alps, there appear at the *Trumsee* some strange-looking deposits. Green sandstone rich in Nummulites, the continuation of the deposits of the Kressenberg, here forms the outermost margin, including the Wartberg, a little mountain which ends abruptly in the lake. Close to the edge of the lake, however, one or two small patches of Chalk with Belemnitella are known, and on the opposite shore there rises from the plain to the south of the village of Fruham a little hill of white limestone, which may be Jurassic [1]. For a very long distance onwards, along the edge of the complex, these fragmentary patches are now altogether absent. It is not till we reach the other side of the Danube, close on the outermost border of the Alps, that we meet with them again. Near *Leitzersdorf*, north of Stockerau, immediately in front of the upturned beds of the Alpine Orbitoides limestone, a blue clay was observed, the rich Foraminiferal fauna of which corresponds, according to F. Karrer, with that of the Senonian of Westphalia, with the Mucronata Chalk of Lemberg, and the Bacculite clay of Bohemia [2]. Not far off a mass of light-coloured limestone, possibly of Jurassic age, rises from the marl and shales of the Flysch zone, here containing numerous erratic blocks. A flaw, with a steep, smoothly polished face, which strikes north-west, cuts off this mass on the south.

Here, close to the outer border of the sunken Flysch zone, a long series of Jurassic hills rises steeply out of the plain and strikes to the north-north-east, past Ernstbrunn, Staats, and Falkenstein to the Polau mountains, also Jurassic, near Nikolsburg. The beds of Nattheim in Württemberg reappear here in their most typical developments, then follow light-coloured Tithonian limestones. The investigation of this range has not yet been completed.

Finally, we reach the Jurassic fragments of *Olomutschan*, near Brünn, which rest partly on syenite, partly on middle Devonian limestone. The

Ortenburg bei Passau; Nova Acta Acad. Leop.-Carol., 1881, XLII, pp. 57, 58. These correspond to the Pläner of Hundorf and Strehlen, to the marl containing Baculites, and to the beds of Kieslingwalda. From this the possibility of a connexion with the German Ocean over Siberia becomes conceivable. In addition the Cretaceous deposits of Siegsdorf, near Traunstein, are said to resemble the beds of Lemberg and of North Germany far more than those of Bohemia and Saxony.

[1] Jurassic fossils have not yet been found. The place is mentioned in F. v. Hauer, Ueber die Eocengebilde im Erzherzogthum Oesterr., &c., Jahrb. geol. Reichsanst., IX, 1858, p. 119; it has been recently examined by Frauscher. The presence of Belemnitella in the lake has long been known.

[2] F. Karrer, Ueber ein neues Vorkommen von oberer Kreideformation in Leitzersdorf bei Stockerau; Jahrb. geol. Reichsanst., 1870, XX, pp. 157–184, 2 pl.

way in which the beds lie shows that the great fault of Brünn and the band of syenite must have existed already at about the middle of the Jurassic period in much the same form as at present. 'In their structure,' writes Uhlig at the conclusion of his study of these Jurassic beds, 'they present the closest resemblance to the Jurassic deposits of Lower Bavaria on the one hand, and of Silesia and Poland on the other, and they must be regarded as the last remains left by denudation of once extensive littoral formations, thus proving that the two regions just mentioned were at one time connected by an arm of the sea, which surrounded the southern border of the Bohemian complex[1].'

Far from this remarkable spot, on the great fault-line of the Riesengebirge and Isergebirge, and extending as far as Saxony, there lies, as we have already mentioned, a band of Jurassic limestone which, accompanied by middle and upper Cretaceous, dips in places beneath the granite, just as was the case between Regensburg and Passau. G. Bruder has shown that the Jurassic limestone of Sternberg, near Zeidler, which forms part of this band, includes the zones of *Peltoceras bimammatum* and *Oppelia tenuilobata*, and possesses other characters which connect this district also with the region of Poland, Moravia, and Lower Bavaria[2].

If we consider this in connexion with the fact that near Brünn older members of the Jurassic system lie horizontally on Devonian and syenite, we shall perceive that, in the north of Bohemia, movements must have occurred along the fault at the foot of the Isergebirge, after those which took place along the fault near Brünn. Further, these Jurassic limestones of Bohemia and Saxony are, as their composition shows, certainly not to be regarded as deposits formed in a long narrow fjord; they are relics of denudation, traces of a far-reaching transgression, preserved from complete destruction by their peculiar position.

We thus see that the Jurassic formation which is lost to sight beneath the Carpathians, near Kurdwánow, not far from Cracow, reappears to the south of the point of contact of Weisskirchen (p. 186, Fig. 24) with similar characters, never accompanied by Lias, but almost always by middle and upper Cretaceous. Everywhere the clays containing *Waldheimia impressa* are wanting, while the zone of *Peltoceras bimammatum* is constantly distinguished by its considerable thickness.

We recognize here, marked by many distinctive characters, the existence of a Jurassic region, which, undisturbed by the forward movement of the Carpathians, stretches from Czenstochau to Kurdwánow and Brünn, from north-eastern Bohemia towards Meissen in Saxony, and along the Danube as far as Regensburg.

[1] Uhlig, loc. cit., p. 145.

[2] G. Bruder, Zur Kenntniss der Jura-Ablagerungen von Sternberg bei Zeidler in Böhmen; Sitzungsber. k. Akad. Wiss. Wien, 1881, Bd. 83, pp. 47–49, 2 pl.

### G. *The Relations of the Alpine System to its Northern Foreland.*

The Russian Platform may be followed with constant characters from the north nearly as far as the outer margin of the eastern Carpathians, beneath which it appears to dip. The several zones of the Sudetes, succeeding each other from west to east, reach the outer border of the western Carpathians; the more resistant Jurassic formation even appears along the folded Miocene foreland, only two kilometers from the edge of the mountains. Cretaceous, Jurassic, Trias, and Carboniferous appear to dip, one after the other, beneath the Carpathians; those formations in the Sudetes, however, which are at present of orographic importance, the Culm and the Devonian, come into contact near Weisskirchen with the border of the Carpathians, and appear to dam back the folds of those mountains by their resistance. These obstructive members of the Sudetes extend southwards from the point of contact as far as the fault of Brünn; but more to the south in Moravia there are almost unmistakable indications of the reappearance of the sunken Jurassic zone.

Where the Alps, to the west of St. Pölten, approach nearest to the great Archaean mass, and the deviation towards the arc of the Carpathians begins, this mass is bare; even those patches of Rothliegende which elsewhere accompany the faulted margin are here unknown. Then follows from Passau on towards Donaustauf a zone of Jurassic deposits which are still constantly marked by some distinctive Sudetic characters, and together with these patches of northern, probably Bohemian, Cretaceous strata. The margin of the mass is overthrust, and both fracture and thrusting are younger than the middle Cretaceous.

The whole of the Trias and Jurassic region which extends from the Fichtelgebirge and Bavarian Forest as far as the Schwarzwald and Odenwald has sunk downwards in larger or smaller fragments, and is at last faulted completely out of sight along the Danube. Along this main fault some large caldron inbreaks occur, such as the Ries and the Höhgau. The mountains which surround the field of subsidence on the east or west rise out of it like pillars or horsts: several fractures extend from it into the ancient rocks of the horsts, where they are only revealed as great dykes of quartz.

The fractures of the subsided region are continued also around the south of the Schwarzwald into the table-Jura, and the manner in which the first wave of the chain-Jura is overfolded may well be regarded (Bötzberg section, p. 113, Fig. 10; Habsburg, p. 114, Fig. 11) as an example of the actual thrusting of one member of the Alpine system over the foreland.

The results of the preceding remarks may be summarized as follows: To the east of the southern end of the Bohemian mass the Alps, together

with the whole arc of the Carpathians, appear to be thrust over two other structural elements, namely, the Mesozoic zones of the Sudetes and the Russian Platform. In the same way to the south of the Schwarzwald the chain-Jura is pushed over the fractured table-Jura. Between the two regions, however, from the Schwarzwald to Regensburg, where we should expect an overfold on to the sunken area of Franconia and Swabia, the whole of that part of this area lying nearest the Alps has subsided along the great fracture of the Danube and been completely withdrawn from sight; it is covered by the plain. It is certainly possible that this fracture was caused by the forward movement of the Alps. The universal subsidence of the Trias and Jurassic region in Franconia and Swabia is, however, independent of the Alps, a fact which is already proved by the repetition of this subsidence in the direction of the Paris basin.

In the whole of this foreland the existence of ancient folds may be proved; cases of overthrusting and pinching in have also occurred since the Mesozoic period, as for example at the Buchberg near Bopfingen, or near Voglarn, or at the foot of the Isergebirge, but there is nothing which could be even remotely compared with the great tangential movements of the Alpine border. The resolution of forces is thus very marked in this district.

We may recall, in passing, Gosselet's theory of the relations of the Belgian Coal-measures and the movement of the *faille du Midi* (p. 143) to the foreland of that country, and Gilbert's view that the cause of the movement in the folded Appalachians is *superficial*, in the subsided Basin Ranges *deep-seated* (p. 107).

We observed above that the subsidence of the Alps near Vienna and the great subsidences of its eastern border, from Graz to the Bachergebirge, must have occurred during one and the same stage of the Tertiary aera, namely, that of the lignite of Pitten and Eibiswald containing *Mastodon angustidens* (p. 136). This is shown by the nature of the Tertiary deposits, which occur within the fractured areas, and rest unconformably against the faults. This stage corresponds in age to the fresh-water Molasse of Oeningen, with which is interstrewn the ash of the volcanos of the Höhgau. It is in particular the terrestrial fauna, which is identical in Pitten and in Oeningen; this is known also as the fauna of Sansans. The terrestrial fauna of the upper fresh-water formation of Steinheim and the avian remains of the travertine of the Ries also belong to the fauna of Sansans, as the investigations of Fraas have shown.

The intra- and extra-Alpine subsidences are thus very nearly of the same age, and it is even possible that they owe their origin to contemporaneous events.

There are some indications that the marginal fracture of the subsidences may be older. Deposits of the first Mediterranean stage are to be met

with on the outer border of the Bohemian mass, extending from Retz past Eggenburg and Horn, where they have been subjected to later disturbances; they occur also in many isolated patches, as at Wiedenfeld near Krems, Melk, Wallsee, Linz, Ortenburg near Passau, and elsewhere, extending nearly as far as the fault of the Danube, to which, as far as we can judge, they are similarly related. These deposits are older than the terrestrial fauna of Oeningen, Steinheim, and Eibiswald; they appear to penetrate just as little into the sunken areas outside the Alps as into those of the Alps themselves.

## CHAPTER II

# THE TREND-LINES OF THE ALPINE SYSTEM

**The northern border of the Alps and the Carpathians. Local overthrusting of the outer border. Curvature of the extremity of the Carpathians. Curvature of the mountains of Western Transylvania. Curvature of the Apennines. Sicily. Mountains of North Africa. Gibraltar. The Betic Cordillera. Spiral arrangement of the trend-lines.**

The variety of outline in the mountain masses which form the northern foreland of the Alps and of the Carpathians stands in striking contrast to the uniformity of the long and gentle curve which marks the northern border of the Alpine chain. This curve may be followed without difficulty, even in regions such as Lower Austria and Moravia, where parts of the outer border have been faulted down.

At the southern end of the Schwarzwald the folds of the Jura mountains override by their inverted frontal margin the subsided table-Jura.

Within the Jura, along the whole of the outer border of the Alps and even of the Carpathians, the forward movement of the mountains is indicated, whatever be the nature of the foreland, by one or more long anticlinal folds in the Miocene. It would be superfluous to recall the anticlinal of the Swiss Molasse; but the difficulties which were long experienced in tracing these folds in the soft and easily destroyed Miocene deposits in the east have lately disappeared, since mining operations carried on in precisely this outer border have furnished the requisite information. Gümbel's transverse section of the valley of the Leitzach shows two or three folds, overturned towards the north, in the lignite-bearing Tertiary beds of the outer border near Miesbach[1]. Far away from this locality, in the salt-mines of Wieliczka, the investigations of Paul have in like manner revealed the existence of two or three sharp folds inverted to the north, which explain the peculiar position of the salt-beds in the Miocene clay[2]. Still further to the east, also on the outer border of the Carpathians, the important ozokerite deposit of Boryslaw lies in an anticlinal of the Miocene salt-bearing clay. Paul justly points out that

[1] Gümbel, Ausflugskarten in das Tertiärgebiet von Miesbach und in den Hochgebirgsstock zwischen Tegernsee und Wendelstein; gewidmet der deutschen geol. Ges., München, 1875.

[2] K. M. Paul, Ueber die Lagerungsverhältnisse in Wieliczka; Jahrb. geol. Reichsanst., 1880, XXX, p. 688.

these two chief productive mining districts of Galicia, the salt-mines of Wieliczka and the ozokerite mines of Boryslaw, have been subjected to a common tectonic movement. 'The same force directed towards the north, which compressed the salt-beds of Wieliczka into steep folds, also raised the anticlinal of Boryslaw and thus created the conditions necessary for the accumulation of a product, the exploitation of which has already produced millions [1].'

As a general rule workable quantities of petroleum are found accumulated in the anticlinals, and the ozokerite and petroleum zone of Boryslaw, as it proceeds far to the east, always follows the outermost border of the mountains; it extends as far as Slobodarungurska and Lucza, that is, to the south of Kolomea; and the same association is continued even much further still, to that part of Wallachia where the Carpathians begin to curve round from a north and south to a north-east and south-west direction, but in this region in much younger deposits—the Congeria and Paludina beds. In the basin of the Slonik, to the north of Buzeu, in the south-eastern part of the Carpathians, the salt-bearing strata are, as Cobalescu informs us, steeply upturned, and the Paludina beds which succeed them unconformably, lie in folds, directed from north-east to south-west, following the curve of the mountains [2].

The folds of the Swiss Molasse lie within the Jura; those of the valley of the Leitzach in Bavaria occur south of Regensburg, and of the place where the great fault of the Danube meets the overfolded and fractured border of the Archaean mass; the folds of Wieliczka lie in the immediate neighbourhood of the Mesozoic zones of the Sudetes, which here appear to sink beneath the Carpathians, and they are continued through the whole region of which the Russian Platform forms the foreland.

A closer examination reveals, no doubt, certain secondary deviations in the otherwise constant course of this outer curve. These are caused by the more abrupt projection of some parts of the chain. In the neighbourhood of the Bodensee, where the Flysch zone passes out of Switzerland into Austria, its eastern continuation advances in a flat sigmoid curve a good way beyond the line of strike of the western portion. To this projection of the outer border there corresponds in the interior of the chain the shear of the Rhaeticon along the Rhine line (p. 140, Fig. 15) and the in-break of the Prättigau.

A similar deviation occurs near Salzburg. The Flysch zone has sunken in, but where it reappears along the Salzach it is plainly seen to have been carried further to the north.

[1] K. M. Paul, Die Petroleum- und Ozokeritvorkommnisse Ost-Galiziens; op. cit., XXXI, 1881, p. 163.

[2] G. Cobalescu, Geol. Untersuchungen im Buzeu'er Districte; Verhandl. geol. Reichsanst., 1882, pp. 227–231.

Another of these displacements, still more sharply marked, is met with near Vienna; at the gorge of the Danube, the outer edge of that part of the Flysch zone which lies to the north of the river advances from two to three kilometers beyond the outer edge of that part which lies on the south.

These displacements have taken place along flaws. They result, like the overturned marginal folds, from tangential movement; but however great the importance of this movement may have been in determining the whole strike and structure of these great zones, yet it has not acted alone, for these regions, apart from the well-known local subsidences, also present long linear faults. Lory, who has made such valuable contributions to our knowledge of the western Alps, even attributes to great subsidence faults the chief part in the formation of this segment of the chain. Two of these faults have been traced by Mojsisovics in the Salzkammergut; but further investigation will be necessary to show to what extent and under what form this tangentially moved mass has also sunken in[1].

### A. *Bending round of the extremity of the Carpathians.*

It is many years since we were led to affirm that the tangential force, not only in the Alps, but in the whole of Europe, had been directed mainly to the north, with deviations to west and east. Later investigations, as we shall see, have entirely confirmed this conclusion as regards the regions we then considered, but fresh observations have since been made, which considerably alter our general conception of the Alpine system.

We had at that time observed that the force which caused the movement was directed in the western parts of the Alps towards the west; in the east of Switzerland, in Bavaria, and as far as Vienna, to the north; in the Carpathians to the north-west, north, north-east, and finally east, so that the strike of the beds then becomes north and south, and the chain thus describes a vast arc.

We have already mentioned that in Wallachia, on the south-eastern margin of the Carpathians, the folds strike to the south-west. Much further to the west, in the valley of Prahova, Flysch has been observed containing *Acanthoceras mamillare*[2], and this appears to complete the circumflexion. The observations hitherto published are not, however, sufficiently complete to enable us to judge of the relations of the Flysch zone at this point to the extremely complicated mountain chain which runs from the rapids of the Danube, across the east of Servia, to the Balkans[3].

[1] E. v. Mojsisovics, op. cit., 1883, p. 3.

[2] Verhandl. geol. Reichsanst., 1877, p. 71.

[3] P. Lehmann has only come upon one anticlinal in the ancient rocks of the Fogarasch mountains; it slopes to the north and south: Beobachtungen über Tektonik und Gletscherspuren im Fogarascher Hochgebirge, Zeitschr. deutsch. geol. Ges., 1881, XXXIII, pp. 109–117, pl. xiv.

In Wallachia also we are still in doubt as to the degree of deflection which the tangential force has experienced, but in Transylvania it has already been determined with certainty for an inner parallel chain. Lóczi has observed here that the mountain mass rising within the curve of the Carpathians in the western part of the province is girdled round on the east, south-east, and south by a folded zone of Flysch, regularly broken through by 'klippen-kalk,' which runs in a curve within the bend of the river Maros[1].

Here the curving round to the south is actually completed. Within the region of Pannonia the tangential movement experiences a deviation of about two and a half quadrants or 225°. This result calls for a fresh examination of the southern extremity of the Apennines.

### B. *Deflection of the extremity of the Apennines.*

The mountains of the Basilicata formed of limestone and sandstone reach the Ionian sea in the Gulf of Tarento; their last branches extend about as far as Spezzano; thence to the south the chain consists of gneiss and older schist, with all the characters of the older rocks of the Alps. We will consider only its most southern part, the mass of the Aspromonte, constricted by the two bays of Squillace and Santa Eufemia.

The western side of the mass has broken in; it consists, as does the crest, of crystalline rocks. On its eastern, or somewhat south-eastern slope, a highly discontinuous zone of schists occurs, only reaching the summit near Sinopoli. On these older rocks appear isolated patches of Tithonian limestone, sometimes containing Nerinea, Cenomanian deposits of African type, and finally, over somewhat greater areas, Tertiary Flysch-sandstone, with a few beds of lignite containing Anthracotherium. All these transgressive deposits are found to the south-east and south of Aspromonte, and extend as far as its southernmost point near Melito.

Both the older crystalline rocks and the zone of schist extend into Sicily, where they form the core of the Peloritan mountains up to and beyond Cape Calavá, as has been so well described by Seguenza[2]. The same transgressive deposits also reappear here, in particular several patches of Cenomanian of African type, which rest on ancient rocks in the neighbourhood of Barcellona. At the same time, however, a well-marked belt of sedimentary beds is added on to the outer edge of the schist zone, and in this may be distinguished the Rothliegende, dolomites

[1] L. Lóczi, Jelentés a Hegyes-Drocsa-Hegységben tett földtani Kirándulásokról; Földtani Közlöny, 1876, 8vo, Budapest, pp. 22, 23.

[2] G. Seguenza, Breve nota int. le formazione primarie e secondarie della prov. di Messina; Boll. Comit. geol. d'Ital., 1871, II, pp. 49, 97, 145 (cf. Note, p. 83), and in particular Cortese, ibid., 1882, p. 348.

of the Trias, Rhaetic beds with *Spirigera oxycolpos*, &c., two or three fossiliferous zones of the Lias, and the Tithonian and Neocomian. Cape St. Alessio in the south-east and Militello in the west best indicate the course of this band. It is succeeded to the south by hills of Tertiary Flysch, the foot of which is covered by the lavas of Aetna.

Although I have had the pleasure of visiting, under the guidance of Signor Seguenza, this remarkable zone, the structure of which more than any other part of the Apennines recalls that of the eastern Alps, I have yet, on account of its comparatively trifling length, not ventured to draw further conclusions from its presence.

Since then our knowledge of the structure of the mountains of Sicily has been considerably extended. Above all, the important investigations of Gemmerallo have brought to light the fact that the Trias of the east coast is prolonged through the Madonies, and then, having bifurcated into two great bands, runs on the one hand along the north coast as far as Monte San Giuliano near Trapani, and on the other towards the south-west nearly as far as Sciacca. In many places it forms the base of a diversified series of Rhaetic, Jurassic, and Cretaceous deposits, and may often be recognized by its fossils, particularly *Daonella* and *Halobia*. The lowest beds appear on Monte Sant' Elia, situated on the north coast near Bagheria, to the east of Palermo [1].

A recent work by Mottura has also shown the existence, to an extent previously unsuspected, of thick masses of Flysch, of 'argille scagliose' with fucoids, of 'Albarese,' sandstone, and Nummulitic limestone distributed over wide areas, both on the southern border of the Madonies, and further to the south-east past Raddusa towards the western edge of the plain of Catania, as well as in the south-west towards Caltanisetta [2].

Even at Boschetello near Vizzini, Neocomian beds rich in Cephalopods have been shown to underlie the Hippurite limestones, which in places are visible towards the south-east as far as Cape Passero [3]. It thus becomes difficult to resist the conclusion that the zone of Verrucano and Trias dipping to the south on Cape Alessio is to be regarded as part of the outcrop of a widely extended zone of limestone.

There can be no doubt as to the original continuity of the Aspromonte in Calabria and the Peloritan mass in Sicily; this is shown by their mutual position, by the bending round of the Calabrian zone of schist

[1] G. G. Gemmellaro, Sul Trias della regione occid. della Sicilia, Accad. di Lincei, 1881–1882, 3a ser., XII. From pebbles pre-Triassic Cephalopods are also known, which approach most closely those of the sandstone of Artinsk: Mojsisovics, Verhandl. geol. Reichsanst., 1882, p. 31.

[2] Mottura, Appendice alla memoria sulla formazione terz. nella zona solfifera di Sicilia; Mem. r. Comit. geol. 1872, II, pp. 5–8.

[3] R. Travaglia, La sezione di Licodia-Eubea e la serie dei terr. nella regione S.E. della Sicilia, Bollet., 1880, XI, pp. 250, 507; Ippol. Cafici, tom. cit. p. 495.

(discontinuous, it is true), and by the identity of the transgressive Cretaceous deposits. From this it follows that the folded sedimentary beds on the outer margin of the Apennines must undergo a sharp curvature to the west beneath a part of the Ionian sea.

We now find ourselves confronted by a fresh problem. In the north-east of Sicily there is a fragment of older crystalline rocks, bordered by a zone of schist, proceeding from Calabria; this is followed by zones of Verrucano, Trias, Rhaetic, and Lias to Neocomian; all are compressed together into a somewhat narrow band, which hardly extends further than Taormina; then follow the Flysch rocks. They appear at first as an imposing independent belt extending into the vicinity of Aetna, then they dip beneath younger sediments, but crop out in places, where the underlying beds of Hippurite limestone and Neocomian also become visible.

It is easy to recognize the continuation of the horizontal younger Tertiary beds on the plateaux of Malta. But the prolongation of the Eocene and Cretaceous rocks lies, as Coquand perceived many years ago, in North Africa[1]. Thence the promontory of Dak'hela with Cape Bon extends a long way towards Sicily; it is composed chiefly of Neocomian and Flysch, as is shown by the outcrops on Cape Bon itself, those near Zaghouan, and on the south side towards the Gulf of Hammamet[2].

It is here, then, that we must continue our comparisons.

## C. *The North African Chain.*

Among the constituents which help to build up the great mountain chain of North Africa, we may first consider *a number of recent volcanic rocks* which emerge here and there as islands off the coast, though in a few places they also occur on the mainland.

We meet first, at some distance from the land, the rugged *island of Galita*, 350 meters in height, accompanied by reefs and smaller islands. The whole island, with the exception of a steep upturned fragment of dark limestone and shale, consists of trachyte and a dark dolerite-like rock[3].

[1] In several places, as, for instance, in Coquand, Descript. géol. de la partie septentr. de l'emp. du Maroc, Bull. Soc. géol. de Fr., 1847, 2e sér., IV, p. 1189, and Sur la format. crétac. de Sicile, op. cit., 1866, 2e sér., XXIII, pp. 497–504.

[2] A. Pomel, Le Sahara, Observ. de géol. et de géogr. phys. et biol. avec des aperçus sur l'Atlas et le Soudan, Publ. de la soc. de climat. d'Alger, 1872, p. 32; G. Stache, Geol. Touren in der Regentschaft Tunis, Verhandl. geol. Reichsanst., 1876, pp. 34–38; Tchihatcheff, Espagne, Algérie et Tunisie, 8vo, Paris, 1880, p. 495.

[3] I follow here the account given by Vélain, Constit. géol. des îles voisines du littoral de l'Afrique, du Maroc à la Tunisie; Comptes rend., 1874, t. 78, p. 73. Renvu long ago published a geological map of the island; he believed the porphyritic varieties of the trachyte to be granite: Explor. scientif. de l'Algérie, 4o, 1848, Géologie, p. 61, pl. ii. Issel has also recorded granite on Galita, and regards this island as a continuation of Sardinia: Ann. Mus. civ, Genova, 1879–1880, XV, p. 250.

Further to the west the prolongation of the volcanic rocks lies on the mainland of Africa; I allude to the basaltic masses of *Dellys* in Kabylia. Still further, to the west of Algiers and the plain of Mtidja, these rocks advance somewhat further into the country. They even appear in the district of *Miliana*, in three separate zones, the first on the sea-coast near Cherchel and other places, the second on the southern border of the first more inland range of mountains formed of Cretaceous rocks, and the third, the most southerly, with a length of more than fifty kilometers at the south foot of the next chain, the great *Sra Kebira*, also formed of Cretaceous rocks[1].

In *Oran* volcanic rocks also occur, in this case trachyte and basalt, intimately associated with younger Tertiary deposits, and even with an inferior division of the Quaternary. Generally speaking the trachytes appear to be older than the basalts[2].

The island of *Habibas* consists of 'millstone' trachyte[3].

Still further to the west, on both sides of the *Wady Tafna*, more considerable masses of basalt occur; on the basalt island of Aïn-Temouchent, on the confines of Oran and Tlemcen, basalt flows cover Quaternary deposits containing land-shells[4].

The *island of Raschgoun* affords puzzuolane and glassy felspar[5].

Large masses of basalt also appear near *Nemours*.

The *Zaffarin Islands* west of Nemours consist of trachyte and phonolite[6]. On the very small island of *Alboran*, which lies at a great distance from the coast, a steeply upturned fragment of a stratified deposit is to be seen, apparently of recent sedimentary origin, and upon this lies a layer of rock containing olivine[7].

This series of recent eruptive rocks may thus be recognized far towards the west on the islands and along the coast.

The next zone, which, with the exception of the little island of Plane, to the west of Oran, belongs entirely to the littoral margin of the continent, is composed of a series of older rocks, gneiss, and ancient granite, mica-schist, and clay slate, with beds of granular marble.

[1] A. Pomel, Descript. et carte géol. du massif de Milianah; Soc. de Climatol. Algérienne, 1872, pp. 130–138.

[2] Bleicher, Recherches sur l'origine des éléments litholog. de terr. tert. et quat. des env. d'Oran, Compt. rend., 1874, LXXVIII, p. 700; and Note sur la géologie des environs d'Oran, Bull. Soc. géol., 1875, 3e sér., III, pp. 187–195.

[3] Vélain, loc. cit., p. 72.

[4] Pouyanne, Notice géologique sur la subdivision de Tlemcen; Ann. des Mines, 1877, 7e sér., XII, p. 138.

[5] Vélain, loc. cit., p. 71; and Sur un feldspath orthose vitreux des pouzzolanes de l'île Rachgoün, Compt. rend., 1874, LXXIX, p. 250.

[6] Vélain, loc. cit.

[7] F. M. Dávila, Isla de Alboran; Bol. Com. del Mápa geol. de Esp., 1876, III, pp. 177–179.

The first mass of gneiss is that of the *Jebel Edough*, west of Bona. It is bordered on the south by Lake Fezzarah. Opposite it, on the west side of the Gulf of Stora, the 'Seven Capes' near Collo consist of granite and quartz porphyry. The zone of schist, which follows to the south, extends from Edough, running fairly parallel to the coast, past Philippeville, and then southwards from Collo and towards Djidjelly in the Gulf of Bougie, where quartz porphyry again becomes visible on the coast [1].

The next mass is the *gneissose mass of the great Kabylia*, west of the Bay of Bougie, which, with the accompanying ancient schists, occupies the whole basin of the Wady Sebaou down to its mouth near Dellys. It rises inland to a height of 1,420 meters, being thus considerably lower than the mighty limestone chain of the Djurdjana, which dominates it on the south, with a height of between 1,730 and 2,517 meters. The gneiss mass of Kabylia is in places covered by transgressive Nummulitic beds, but remains exposed to view in three larger mountain groups, the most southerly of which includes ancient schists, and measures fifty-four kilometers from east to west, with a mean breadth of sixteen kilometers. Towards Dellys and the sea-coast it appears to be completely covered with Tertiary deposits [2].

The next outcrop of ancient rocks is particularly significant as regards the manner in which those parts of this great mountain chain now buried beneath the sea have given way and sunken down. Just as in Italy the peninsula of Sorrento, with the island of Capri, projects as a horst between the Bay of Naples and that of Salerno, thus separating two independent sunken areas, so here two peninsulas project into the sea, to the east and west of the Bay of *Algiers*; in the east Cape Matifou, in the west the peninsula of Bouzaréa, and each of these promontories is formed by a fragment of the schistose series which covers the sunken mass of Algiers. This at least is the only interpretation I can put upon the many descriptions which have been made of this region. On Bouzaréa the mass of older rocks exposed to view is much more considerable than on Cape Matifou; we see there a series of garnet-bearing mica-schists, talc-schist, and clay slate, with an intercalation of dark blue limestone of considerable thickness; intervening gneiss-like bands and small isolated masses of

[1] Coquand has given an extremely detailed description of the Edough, Descr. géol. de la prov. de Constantine, Mém. Soc. géol. de Fr., 1854, 2e sér., V, p. 12 et seq.; for the schist zone see L. Hardouin, Sur la géol. de la subdiv. de Constantine, Bull. Soc. géol. de Fr., 1868, 2e sér., XXV, p. 328, pl. v; also Parrant, Carte géol. du dép. de Constantine par Tissot, op. cit., 1882, 3e sér., X, pp. 299–306.

[2] A. Péron, Sur la constit. géol. des montagnes de la grande Kabylie. Sur les roches du massif d'Alger et d'autres points du littoral afric.; Bull. Soc. géol. de Fr., 1867, 2e sér., XXIV, pp. 627–652; note by P. Marès, op. cit., 1867, 2e sér., XXV, p. 135, and in particular L. Ville, Études géol. faites dans la Kabylie, op. cit., XXV, pp. 251–276, pl. iii.

granite also rise within the schists, resembling those which are met with in the Edough and on the Peloritan mountains. Near Algiers the dip of the beds is to the south, and increases in amount as we proceed in that direction. On the summit of Bouzaréa the strike bends in an arc. This fragment is separated by the plain of Mtidja from the limestone mountains on the south[1].

Still further to the west, on the west side of the Bay of *Mostaganem*, in the littoral belt of the province of Oran, granitic rocks, finely plicated clay slate with silken lustre, limestone, and dolomite containing calamine appear below a group of red slates and quartz sandstone. These ancient rocks form many projections on the shore west of Oran, and, proceeding in the direction of the coast, appear, according to Bleicher, in the hills to the south of Nemours[2].

Still further south of Nemours, towards Oudjda, a long ridge of ancient rocks rises up in an anticlinal, which strikes across the frontier of Morocco, following the direction of the chain. In this locality also isolated masses of granite protrude through the schists[3]. In the eastern part of the mountains such deep-seated rocks are never, so far as we know, brought to the surface.

If we follow the sea-coast into Morocco we shall find, according to Coquand's painstaking observations, the following facts. While the mountain folds of Tlemcen, which we have mentioned above, extend inland in a west-south-west direction, a series of outcrops of older rocks is confined to the curve of the littoral region and does not penetrate further into the country. The oldest members appear on the promontories; for example, on the prominent Cape *Ras-el-Deir* (Cabo tres Forcas) near Melilla. *Ras Torf* (Cabo Negro), to the north of Tetuan, derives its name from its dark garnet-bearing mica-schist, which is associated with clay slate and later veins of granite. These older rocks also form the promontory of *Ceuta* which branches off from the Jebel Mousa.

In this way then the ancient rocks which extend along the south coast of the Mediterranean reach the Straits of Gibraltar; on the landward side they are bordered by a band of Palaeozoic sediments which, from Tetuan past the Riff, appears to form the greater part of the littoral region lying on the inner side of the fragments of still older formations mentioned above.

[1] Renou, Description géologique de l'Algérie, pp. 66–74, section of the promontory, pl. iii, fig. 22; P. Marès in Bull. Soc. géol. de Fr. 1861, pp. 365–368, et passim. Cape Matifou has lately been discussed in greater detail by Tchihatcheff in Espagne, Algérie et Tunisie, p. 206 et seq.

[2] Pouyanne, op. cit., pp. 84, 135.

[3] Bleicher, Recherches sur les terrains antérieurs au Jurassique dans la prov. d'Oran; Bull. Soc. géol. de Fr. 1880, 3e sér. VIII, pp. 303–309. Here, too, contact phenomena between granite and schist do not seem to be wanting, e. g. near Nedroma on the road south-east of Nemours; schists containing chiastolite and andalusite occur in this region.

At one locality near Djaritz, above Tetuan, Coquand has found remains of Trilobites, Orthoceras, Orthis, &c., in a higher stage of this zone. Its strike passes gradually from east-north-east and west-south-west to south and north[1].

Apart from isolated exposures of Carboniferous limestone, which are mentioned by Bleicher as occurring in Oran, the next zone is composed of a dark red conglomerate or red sandstone, in which fossil trunks of trees have been found. Pomel assigns this zone to the Permian, Bleicher regards it as still forming part of the Carboniferous. It appears above the schists, and below the Mesozoic limestones in the northern part of the province of Constantine, then on the Jebel Khar, i. e. the Mountain of the Lions, near Oran, on Cape Falcon, above the schists of Eastern Tlemcen and in other places. In the west a crescentic curve of red sandstone, visible a long way off, forms, from Tetuan onwards, and as it would appear throughout the Riff, a border to the littoral zone of ancient schists. It is quite possible that this red Permian series corresponds to that thick succession of red beds in the south of Morocco, and of the great Atlas to which Fritsch has given the name '*the Wansero sandstone*[2].'

Above this red-coloured series lie the thick limestones of the high mountains. That the lowest part of these, at least in the east, belongs to the Trias is proved, in spite of the absence of fossils, by the presence of overlying Lias, which has been recognized by numerous observers[3]. Lias is known at several localities in the northern part of the chain; Jurassic deposits are more largely represented, but the Cretaceous and Eocene play the chief part in the structure of its mighty folds. The chain is bounded on the south by the basin of the Hodna and by a series of shotts. From Tunis its direction for a long way onwards is to the west-south-west, until, in the Riff of Morocco, that curvature to the north occurs which we have already recognized in the inner zones, and which closes the basin of the Mediterranean.

This bending round explains the fact that *Cape Spartel*, according to Coquand, consists of Flysch, and that Desguin and Lenz have met with no deposits older than the upper Jurassic over the whole distance from *Tangier* to *Mekinez* and *Fez*, and that the only Mesozoic fossils which Desguin found south of Tangier belong to the horizon of *Ostraea scyphax*[4].

[1] H. Coquand, Description géologique de la partie septentrionale de l'empire du Maroc; Bull. Soc. géol. de Fr., 1847, 2e sér., IV, pp. 1198-1205. Lenz lately recorded micaceous slate near Ceuta: Mittheil. der afrikan. Ges., 1880, II, p. 76.

[2] K. v. Fritsch, Ueber die geol. Verhältnisse von Marokko; Zeitschr. ges. Naturwiss., 1881, 3. Ser., VI, p. 204.

[3] In particular Coquand, Province de Constantine, pp. 44-60; Maroc, p. 1218.

[4] Mourlon, Esquisse géologique sur le Maroc, 18 pp., from the Bull. de l'Acad. roy. de Belgique, 1870, 2e sér., XXX (according to collections made by Desguin); Bleicher,

In the regions situated within French territory a vast deal has already been accomplished in the disentanglement of the folds of the limestone chain; indeed, the success with which French geologists have interpreted the structure of the mountain chains of North Africa may be counted among the most gratifying achievements of descriptive geology, and redounds greatly to the honour of all who have contributed to it.

It is not necessary to enter here into the details of the folded structure; but it is worth mentioning that, according to the fine maps of Brossard, folding characterizes the transverse chain which occurs in the region of Bou Sada to the south-west of the Hodna, and connects the mountains lying to the north of the Sebchas with those to the south. The folds have the same direction as those of the main chains and are thrown down by a transverse fault.

The folds strike through the mountains to the north of the Sebchas with a regularity which recalls those of the Jura; and along the margin very young Tertiary deposits appear, which have suffered the same disturbances [1].

To the south of the plain of the Sebchas the folded chains rise again to considerable heights, but no deposits have been observed in them older than the upper Jurassic. This is covered by the Neocomian; then follows, at about the horizon of the Gault, a great thickness of Flysch-like sandstone and upon this the middle and upper Cretaceous. The Cenomanian consists of gypsum, marl, and limestone; the upper zones of the Cretaceous consist of limestone. Towards the east Eocene also appears.

From Figig, far in the west on the borders of Morocco, to beyond Laghouat, where it is known as Jebel Amour, the chain ends in a steep rectilinear face overlooking the boundless Sahara, its beds striking to the north-east, as is shown by the observations of Rolland; its outer margin consists of Cretaceous limestones inclined to the south-east, forming the outer flank of a great anticlinal. Towards Biskra the boundary is less rectilinear, but the structure of the chain remains the same [2].

We must thus recognize a number of parallel zones in the North

Sur la géologie des régions comprises entre Tanger, el Araich et Meknès, Compt. rend., 1874, LXXVIII, pp. 1712-1716.

[1] Brossard, Constitution physique et géologique de la subdivision de Setif, Mém. Soc. géol. de Fr., 2e sér., VIII, p. 271, pl. xx, for the southern border in the Setif, particularly in the depression of Zahrez; for the western part of the region of the Nahr Uassal, Bourguignat, Études géologiques et paléontologiques des hauts plateaux de l'Atlas entre Boghar et Tiharet, 4to, Paris, 1868, where, p. 33, a gentle anticlinal is described, involving Quaternary deposits.

[2] G. Rolland, Sur le terrain crétacé du Sahara septentrional, Bull. Soc. géol. de Fr., 1881, 3e sér., IX, pp. 510-515. For the southern border of the Aoures mountains, see Dubocq, Mémoire sur la constitution géologique des Zibân et de l'Ouad R'ir, Ann. des Mines, 1852, 5e sér., II, pp. 249-330, and for the following part extending to the west and far into the desert, Ville, Exploration géologique du Beni Mzab, du Sahara et de la région des steppes de la province d'Alger, 4to, Paris, 1867.

African chains. The first is the volcanic zone, rising for the most part as islands from the sea, and represented, from the island of Galita in the east to the Zaffarin Islands in the Bay of Melilla in the west, by a number of isolated points. The second zone, frequently projecting into the sea in the form of promontories, consists of more or less fragmentary masses of gneiss, granite, and ancient schists. It extends from the Edough to the long *Ras-el-Deir*, following the curve of the coast as far as the Pillars of Hercules. The relations of the several members of this zone were recognized long ago by French geologists, and Pomel has given an excellent account of them in a general description of the chain[1]. Above the schist series lie red conglomerate and sandstone, held to be either Permian or Carboniferous; then rise the high, abrupt, and lofty scarps of the folded limestone chain, which extends southwards as far as the Hodna and beyond it to the Sahara. *The structure of the Apennines is thus repeated in North Africa, but the outer border of the chain is here turned towards the south.*

In this case also the zone of crystalline rocks has broken down and sunk inwards, leaving but few remains, and the folded chains have been dammed back against the interior of the land; here also volcanic rocks mark the region of in-sinking, which has taken place, as on the west coast of Italy, not along a straight line but in isolated caldrons—as is indicated by the promontories, the last fragmentary remains of the ancient zone.

The lofty Atlas, in so far as it is known, appears to differ greatly, not only in strike but also in structure, from the preceding chains, which follow the coasts of the Mediterranean. It diverges from the northern range, which turns to the north near Gibraltar, and striking away to the west-south-west, reaches the Atlantic coast at Cape Ghir.

### D. *The Betic Cordillera.*

The North African chains in the Riff and as far as the Pillars of Hercules swerve in great arcs to the north and thus bring us back to Europe.

The south of Spain falls into three natural divisions; the first is the region of the Betic Cordillera, which follows the coast of the Mediterranean, striking to the east-north-east; then comes the valley of the Guadalquivir, running in almost the same direction; and on the other side of this river lies the sharply defined southern border of the great Iberian Meseta, which follows the same direction. This vast highland district closely resembles the Bohemian mass, or the Central Plateau of France, sharing with them a number of fundamentally important characters, such as the extensive occurrence of Archaean rocks, the existence of numerous gaps in the Mesozoic series, the intersection by its margin of the

[1] Coquand, Constantine, p. 43, et passim; Pomel, Le Sahara, p. 26.

strike of its rocks, and the transgression of the Cenomanian, which makes its appearance a little further to the north. The Sierra Morena, its most important member in the south, is related to its outer border in much the same way as the Mannhart mountains in Lower Austria are to the southern margin of the Bohemian mass.

We will first turn our attention to the Betic chains, and in describing their structure I will adopt the same method as that just employed in the case of the chains of North Africa; and we will again approach the mainland from the Mediterranean, examining and following up each zone in succession.

In that part of the mainland which extends furthest to the south, *Cape Gata*, we meet with a fairly extensive chain of young volcanic rocks, which form the south-eastern coast of the province of Almeria as far as the neighbourhood of Mojacar, and continue from this town in isolated exposures to beyond Vera in the north-east [1]. Smaller masses of volcanic rocks are visible still further to the north-east near the coast; and to the east of Cartagena, according to Botella, the tongue of ancient schists which terminates in Cape de Palos is separated from the mainland by a chain of volcanic hills. The little reefs in the Lagune Mar Menor near Cartagena also consist of trachyte and basalt [2].

Thus the whole of the south-eastern border of the Iberian peninsula, from Cape Gata to Cape de Palos, is occupied by recent volcanic formations; and consistently with this no part of the coast, with the exception of the neighbourhood of Lisbon, is subject to more violent or more frequent earthquakes [3].

The volcanic zone is succeeded towards the interior by a very extensive complex of schists, including a small amount of gneiss; its chief components are garnet-bearing mica-schists, talc-schists, and clay slate, and beds of crystalline limestone. This mass or band of schists begins in the east with the already mentioned ridge between Cape de Palos and Cartagena, appears in isolated outcrops to the north of this town, and is continued to the south-west. It then forms several very great anticlinals, which strike from east-north-east to west-south-west. The first of these is the Sierra Alhamilla, the next, to the north of this, the broad Sierra de los Filabres [4]. Then follows the greatest of these arches, the

[1] F. M. Donayre, Datos para una reseña física y geológica de la region sudeste de la Prov. de Almeria; Bol. Com. Mápa geol. de Esp., 1877, IV, pp. 16–31.

[2] F. de Botella y de Hornos, Descripción geológica minera de las provincias de Murcia y Albacete, fol., Madrid, 1868, detailed map of Cartagena, p. 43.

[3] It is sufficient to recall the earthquake of June 10, 1863, which convulsed the valley of the river Almanzora, and was followed by a long period of disturbance: C. de Prado, in Perrey, Tremblements de terre en 1863, pp. 139, 172, et seq.

[4] F. M. Donayre, op. cit., pp. 31–50; L. N. Monreal, Apuntes físicos y geológicos referentes a la zona central de la provincia de Almeria, Bol. Com. Mápa geol., 1878, V; pp. 54–76.

mighty *Sierra Nevada*. This, according to the statements of Ansted [1] and Drasche [2], consists of a simple anticlinal, which gradually increases in height towards the west and then ends abruptly. It is composed of mica-schist, clay slate, and ancient limestone. Gonzalo has lately described this great mass in detail, and has shown that it finds its further continuation to the south-west in the precipitous Sierra de Almijara near the coast [3].

The Sierra de Gador, an isolated mass of Trias, famous for its rich mines of lead and zinc [4], rises, west of Almeria, between the south-east part of the Sierra Nevada and the sea.

The zone of ancient schist extends far into the province of Malaga to beyond Marbella, where a great mass of serpentine appears, accompanied by gneiss, granite, and Archaean schists. This, according to MacPherson's detailed description, forks to the north-east, constitutes on this side part of the semicircular border of the Hoya de Malaga, and forms on the south-west the most extensive, if not the highest part of the Serranía de Ronda. It descends precipitously to the sea, but near Marbella a narrow faulted band of schists and Mesozoic beds may still be seen along the shore. A band, equally affected by faults, of intensely folded dolomites, which are considered to be of Palaeozoic age, accompanies the ancient rocks of the Serranía de Ronda; west of Marbella, near Manilba, the serpentine and the dolomites terminate near the sea-coast [5].

Here lies the limit of the ancient rocks in the Betic Cordillera. No organic remains have ever been found in this vast zone of schist, although opposite to the Cordillera, on the border of the Meseta, e.g. near Alcaráz, in the province of Murcia, the presence of Silurian fossils was pointed out many years ago by Verneuil. This zone of schist, recalling in so many respects the Alps, is followed by a zone of Mesozoic and Eocene age, which is intersected by numerous faults and highly folded.

Let us first consider the isolated limestone mass of *Gibraltar*. Ramsay and Geikie, when studying this promontory, also visited the opposite shore of Africa; they found, near Ceuta, the ancient clay slate mentioned above, dipping to the west, and convinced themselves that the Jebel Mousa above Ceuta, i.e. the second Pillar of Hercules, corresponds

[1] D. T. Ansted, On the Geology of Malaga and the Southern Part of Andalusia; Quart. Journ. Geol. Soc., 1859, XV, p. 588.

[2] R. v. Drasche, Geologische Skizze des Hochgebirgstheiles der Sierra Nevada; Jahrb. geol. Reichsanst., 1879, XXIX, pp. 93–111.

[3] D. Joaq. Gonzalo y Tarin, Reseña física y geológica de la provincia de Granada; Bol. Com. Mápa geol., 1881, VIII, in particular p. 13 et seq., sheet A.

[4] The same, Edad geológica de las calizas metalíferas de la Sierra de Gador; op. cit., 1882, IX, pp. 97–111.

[5] J. MacPherson, Relacion entre las formas orográficas y la constitución geológica de la serranía de Ronda, 8vo, Madrid, 1881, 34 pp. and map.

with the Rock of Gibraltar, both as regards the nature of the rocks and their strike. We must therefore conclude that the limestone zone, in all probability Jurassic, extends across from Africa to Europe. The limestone of the Rock of Gibraltar itself, which is cut through by a great fault, strikes first south and north; further to the north it turns more and more to the north-east [1].

Proceeding in this direction we reach the northern part of the Serranía de Ronda, which is composed of Mesozoic limestone and Eocene beds highly folded and traversed by numerous strike-faults. We have already referred to its southern part, composed of Archaean or Palaeozoic rocks. The Serranía de Ronda is the subject of several compendious works by MacPherson [2], in which for the first time the fact is insisted upon, that the whole chain of North Africa has been formed by a movement directed to the south or south-east, and not towards the north [3].

The Betic Cordillera must be regarded as a mountain range folded by a force acting in a north or north-westerly direction: 'the imposing phenomena of folding, fractures, and asymmetric structure which prevail in all sierras composing the Cordillera Bética, appear to me,' says MacPherson, 'to result solely from the action of a prodigious lateral pressure, which forced this part of the earth's crust against the passive mass of the Meseta of Central Spain [4].'

The faults which traverse the Serranía de Ronda, and which seem in certain cases to have brought the intensely folded zones of the chain into a very abnormal position with regard to one another, are in no way opposed to this conception, the main features of which are already indicated by the distribution of the rocks. It receives additional confirmation from the observations made further to the north-east, particularly from the section of the Sierra de Abdalagis to the north of Alora in the province of Malaga, published by Orueta [5]. The Mesozoic zone is here continued to the east-north-east past Lorca and Murcia, and

[1] A. C. Ramsay and J. Geikie, On the Geology of Gibraltar; Quart. Journ. Geol. Soc., 1878, XXXIV, p. 513. Owing to the occurrence of a species considered to be *Rhynchonella concinna*, the limestone of Gibraltar is assigned to the Jurassic. In the west the superposed shales and sandstones of S. Roque and Algesiras, which also appear in the great fault of the Rock of Gibraltar, probably form the continuation of the lower Cretaceous and the Flysch of the neighbourhood of Tangier.

[2] MacPherson, Breve noticia acerca de la especial estructura de la Península Ibérica, from the Ann. de la Soc. Esp. de Hist. Nat., 1879, VIII, 26 pp.; Estudio geológico y petrográfico del norte de la provincia de Sevilla, Bol. Com. Mápa geol., 1879, VI, in particular pp. 156–172; Uniclinal Structure of the Iberian Peninsula, Ann. de la Soc. Esp. de Hist. Nat., 1880, IX; cf. also note 5, p. 229.

[3] MacPherson, Uniclinal Structure, pp. 24, 25.

[4] MacPherson, Sevilla, p. 171.

[5] Dom. de Orueta, Bosquejo físico geológico de la region septentrional de la provincia de Málaga; Bol. Com. Mápa geol., 1877, IV, sheet D.

to the north of these towns, and, although frequently interrupted by young Tertiary plains, it reaches the sea in the province of Alicante.

The outer northern border of the Betic Cordillera is accompanied in the valleys of the Guadalete and the Guadalquivir by intensely folded Tertiary deposits. These finally sink beneath the plain; then follows the alluvial land of the Guadalquivir, and, near Seville, we reach the precipitous border of the Sierra Morena and of the Central Meseta.

Proceeding inland from the Mediterranean we thus meet in this part of the Iberian peninsula, first a group of younger volcanic formations, extending from Cape Gata to Cape de Palos, then a zone of ancient schists striking to the east-north-east, and including the serpentine mass of the Sierra de Ronda with the older rocks accompanying it. The most conspicuous component of this zone is the Sierra Nevada, which extends from Malaga to Cape de Palos. It is followed by a zone of Mesozoic limestone and Eocene beds, which is continued from the Rock of Gibraltar with an arcuate strike, through the northern parts of the Serranía de Ronda, towards the Sagra Sierra into the province of Alicante. Outside this zone lie the folded Tertiary beds of the plain of the Guadalquivir, then follows the river itself, and on the opposite side rises the Meseta.

This is the same succession of zones as that which we have encountered, with trifling local differences, in the north of Africa, in the Apennines, and in the Carpathians. The Betic chain turns its in-sunken inner border, on which volcanic eruptions have taken place, to the Mediterranean; its folded outer border is turned towards the Meseta.

Whether this chain, as has been often supposed, finds its continuation in the Balearic Isles, I cannot, in view of its complicated structure, venture to decide, notwithstanding the excellent memoirs which have been published on these islands.

### E. *The arrangement of the trend-lines.*

The remarkable correspondence in the structure of all these chains, and the peculiar and repeated deflexion of the folds which form them, invite an attempt to trace and describe, disregarding all subsidiary deviations, the chief lines of strike, the guiding lines, as it were, of those great folds of the earth's crust in Southern Europe which have collectively received the name of the Alpine system.

The accompanying illustration (Fig. 26) represents in a rough and very diagrammatic manner the result of such an attempt.

The Jura mountains form an arc of a circle with its convex side turned towards the north-west; its termination on the south lies decidedly nearer the northern Alps than that on the north-east. The movement of the folding has been directed towards the exterior.

The Alps begin to the west of Genoa; the curve described by their

folds extends first to the north, then more and more towards the east. Several concentric trend-lines have been marked here to represent the congregation of several chains in this region. The most northerly of these lines bends round the southern end of the Bohemian mass and forms the arc of the Carpathians, which encroaches upon the Sudetes and the Russian Platform. On this line also the movement is constantly directed outwards, first to the west and north, as in the Jura, then gradually bending round from the north again to the north-west in Moravia, to the north in Galicia, and, finally, to the east and south-east in Moldavia and Wallachia.

Another trend-line leaves the Alps, and extends along the Plattensee to the north-east. This is the line of the Mittelgebirge of Hungary; the movement here was directed to the north-west.

In Transylvania we have marked within the curve described by the

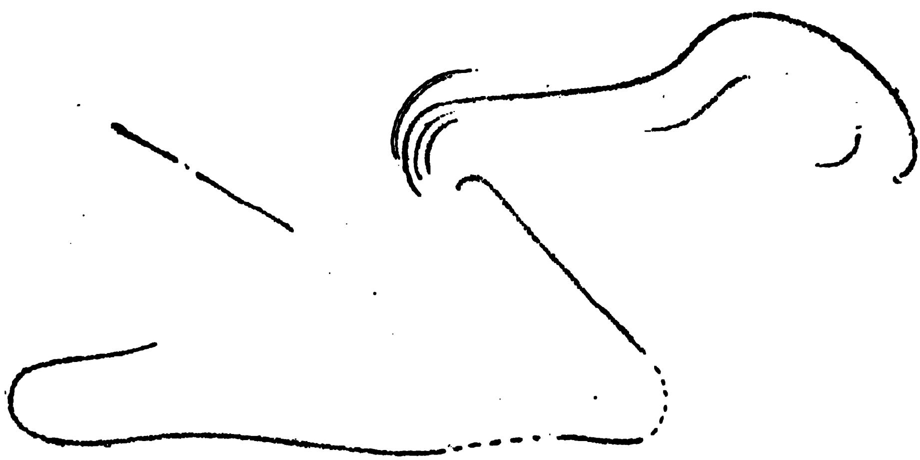


FIG. 26. *Diagram of the trend-lines of the Alpine system.*

river Maros an arc, convex towards the east and south; this is the border of the Transylvanian Erzgebirge (ore-bearing mountains). Here again the folding force was directed outwards, i. e. to the east, south-east, and south.

Toula's latest observations in the western Balkans reveal a structure so extraordinarily complex, that I cannot at present undertake to extend my remarks to these mountains [1].

The Apennines appear to begin in the Gulf of Genoa with a curve convex towards the north, the chain then trends to the south-east; the folding force was directed to the north-east.

In Sicily we have drawn a line nearly due east and west; it represents a chain, of which the Archaean core, corresponding with that of the

[1] F. Toula, Grundlinien der Geologie des westlichen Balkan; Denkschr. k. Akad. Wiss. Wien, 1881, XLIV b, pp. 1–56, pl. i–iv, and map.

Calabrian mountains, is visible in the north-eastern part of the island; here the folding force was directed to the south.

This segment is continued into the north of Africa by a line running to the west-south-west; in the west it curves round towards the north. On this line the folding is directed to the south, and then in correspondence with the bend of the strike more and more to the west.

This bend passes across the Mediterranean to Europe near the Pillars of Hercules, and seems to furnish a complete connexion between the folds of North Africa and those of the Betic Cordillera.

The trend-line of the Cordillera strikes to the east-north-east; the folding is directed to the north-north-west.

If we regard the ancient masses, from the Russian Platform to the Iberian Meseta, as the northern boundary of the Alpine system, then the series of the principal folds terminates with the Cordillera. But alien masses are also present in the interior of the chains; that of Servia-Croatia, lately pointed out by Mojsisovics, is an example; we might therefore include the Pyrenees in this system, and we shall then obtain a long line running approximately west-north-west to east-south-east, in which the folding force appears to have been directed to the north-north-east.

We thus obtain a series of lines arranged spirally in a very peculiar manner, and, with the exception of the Pyrenees, all folded in the same direction. The centre of this spiral lies to the south-west of Genoa [1].

So long as we confine our attention to those parts of the Alpine system which are situated in Europe, they appear, with some trifling exceptions in the extremities of the chains, to be folded towards the north-west, north, or north-east. But in Sicily this is no longer the case; and if we include, as we must, the North African chain in the system, we transform the scheme completely.

The considerations which have guided us in determining these great curves demand some further explanation. On account of the constant course of the outer margin of most of the chains, and the frequent interruptions to which the inner zones are subjected, we have chosen as data for the construction of the curve the external outline, as well as the strike of the outer folded Mesozoic zone taken at about the middle. For this reason the great dislocation which, for example, extends within the Alps from the Upper Tessin towards the north-east, is not represented. The direction of the Rhaetic zone in Corsica has been determined by Dieulafait, and Lotti has shown that the serpentines

[1] H. Habenicht, Die Grundzüge im geologischen Baue Europa's, 8vo, Gotha, 1881, may also be mentioned, because this work contains (pl. 3) the first attempt known to me to represent on a map the lines of folding of the Alpine system. This attempt is, it is true, incomplete and partly erroneous, owing to the author's mistaken conception of the Apennines.

of Corsica are of the same age as those of the Maritime Alps and of Liguria, and that they are perhaps only the continuation of the serpentines of the Alps, which extend as far as Elba, and perhaps still further to Giglio and Mont' Argentario. Hence the opinion has gained ground that the true continuation of the ancient Calabrian rocks must be looked for in Corsica [1].

Without wishing to anticipate further investigation, I may observe that the course of the exterior outline of the Apennines is not in accordance with this explanation; that, so far as existing observations extend, it seems much more likely that Corsica presents us with fragments of an independent chain on the way to join the inner side of the Apennines; and, finally, that even if this last view should prove to be correct, it would involve little modification in the disposition of the curves we have drawn, which are based on the strike of the outer zones [2].

The observations made in Corsica render it all the more remarkable that in Sardinia the characters which distinguish an extra-Alpine region acquire more and more prominence, as in particular the occurrence, proved by Bornemann, of transgressive extra-Alpine Trias in the south-western part of the island; this appears to me to recall the red transgressive deposits of the Iberian Meseta [3].

There are thus many important questions concerning this part of the Mediterranean region which still remain open to investigation.—

There still remain two important facts deserving especial emphasis.

First, the striking correspondence between *the western part of the basin of the Mediterranean and the Hungarian plain.* Each of these regions lies within the curve described by a great fold of the earth's crust, surrounded by a number of sunken areas of greater or less extent; each is occupied by volcanos and encroaches more or less on the girdles of Palaeozoic, Mesozoic, or Flysch deposits which, more or less clearly defined from each other, compose the folded rampart.

Secondly, that in spite of the evidently recent age of many of these great general movements, the mountain system itself evidently does not belong wholly to a recent period. Where the older rocks are exposed *transgressions* occur, which in many respects recall the trangressions on the horsts of the foreland.

Middle and upper Cretaceous and Oligocene mark two of the chief

[1] Hollande, Géologie de la Corse, Ann. des sciences géol., 1877, IX, Art. 2, 114 pp., pl. viii–xii; Dieulafait, Serpentines de la Corse, leur âge et leur origine, Compt. rend., 1880, XCI, pp. 1000–1008; H. Reusch, Note sur la géologie de la Corse, Bull. Soc. géol. de Fr., 1882, 3e sér., XI, pp. 56–67; B. Lotti, Appunti geologici sulla Corsica, Bol. Com. geol. d' Italia, 1883, 2a ser., IV, pp. 65–73.

[2] C. J. Forsyth-Major, Die Tyrrhenis; Zeitschr. Kosmos, 1883, VII, p. 104.

[3] C. G. Bornemann, Sul Trias nella parte meridionale dell' isola di Sardegna; Boll. Com. geol., 1881, 2a ser., II, pp. 267–275, 2 pl.

stages of transgression in extra-Alpine Germany. In Carinthia and to the west of Graz Cretaceous beds lie immediately on the Devonian and still older rocks. In Carinthia and Carniola Oligocene deposits of the age of the beds of Sangonini and Castel Gomberto penetrate into the region of the Trias limestones and crystalline schists. On the Col de Chaberton in the Cottian Alps limestones of the Cretaceous system lie within districts, the rocks of which are believed to be very ancient. Near Genoa a great mass of Oligocene Flysch lies on granitic rocks; the lignite beds with *Anthracotherium magnum* near Savona rest immediately on granite, being themselves covered by the Flysch. I have already mentioned the transgression in the east of Calabria and the encroachment of the Cenomanian of African type on the granite in the north-east of Sicily. The Flysch extends partly over the mass of Kabylia.

Within the great curves also we find isolated areas, in which transgressions are equally visible. Along the in-sunken interior border of the Carpathians, on the isolated masses of gneiss and mica-schist which appear in the north-west of Transylvania, to the south of the trachyte mountains of Nagy-Banya, the transgression begins with patches of upper Cretaceous[1]. In Croatia near Fünfkirchen, and in several parts of South Hungary, a number of characters which are thoroughly extra-Alpine are met with.

It is precisely this fact, the recurrence of certain transgressions within the great trend-lines of the mountain chains and even on the older zones of these chains themselves, as in Carinthia and Sicily, which is of essential significance and which cannot be fully appreciated without comparing the Alpine system with other chains.

The Alpine system of lines is not entirely without parallel in other parts of the world. The nearest approach to such an arrangement is to be found, as far as we can at present judge, in the mountains which surround the Caribbean Sea.

It now remains to trace the trend-lines of other great mountain ranges. Before attempting this task, however, we must pass to the consideration of that great sunken area which forms the floor of the Adriatic Sea, and extends, with its great lines of fracture overthrust towards the interior, past Lake Idro as far as Meran and Idria in the Alps. This sunken area determines to a large extent the relations of the Dinaric chains (not represented on Fig. 26) to the Alps.

[1] C. Hofmann, Bericht über die im Sommer 1882 im südöstl. Theile des Szathmárer Comitates ausgeführten geol. Specialaufnahmen; Földt. Közlöny, 1883, XIII, p. 106.

## CHAPTER III

# THE BASIN OF THE ADRIATIC

**Significance of the Adamello. The Judicarian line. Fractures of the Cima d' Asta. Region between the Judicaria and the fracture of Schio. Dislocations on the north of the fractures of the Cima d' Asta. Fractures of the Drau and the Gail. Dinaric fractures or fractures of the Karst. Recent extension of the Adriatic Sea. Summary.**

A uniform and constant curve marks, as we have seen, the northern border of the Alps; it may easily be followed even where, as in Lower Austria and Moravia, parts of the outer border have been faulted down; the northern border of the Carpathians forms the continuation of the curve.

Attention has often been directed to the contrast between the outer border of the Carpathians and the broken-down inner border with its accompaniment of great volcanic outflows; but the contrast between the northern and southern border of the Alps is equally great, so that for considerable intervals a doubt may be felt as to where the southern border should be indicated on the map.

If we ascend the cathedral of Milan in the early morning we shall see, extending from the Maritime Alps on the left, far away to the broad mass of Monte Rosa to the right, and even beyond it, a noble circle of white peaks and crests surrounding the fertile plain. Here, it is true, the southern border of the Alps is sharply defined, and here too the distinction between the rocks of the northern and southern border is best marked. This broad crescent is formed of ancient rocks, and B. Studer recognized in it many years ago the fractured border of a large sunken area, which lies below the plain of Lombardy. The isolated hills of the Superga, south of Turin, with their beds dipping to the south, are the only fragment of this sunken mass which remains above the ground.

It is near Lake Maggiore, on the southern border of the mountains, that a marginal belt of Mesozoic and Tertiary beds begins to acquire some degree of importance. If we consider its outer limit as the southern border of the Alps it will lead us through Como and Bergamo towards Brescia; to the east of this last town we hesitate whether or not to follow the naked and Karst-like hills of lower Lias which border the plain on the north-east as far as Salo on Lake Garda. We will not follow them, but continue in the same direction to the east-south-east through Como, Bergamo, Brescia. This leads us from the south of Lake Garda towards

LAGO DI CAMPO AND PASSO DELLA FORCELLINA ADAMELLO, SOUTH TYROL

The lower Trias limestone, converted into white marble containing silicates characteristic of contact alteration, is seen extending from the Forcellina down to the lake

On the left, Tonalite ; on the right, plunging vertically downwards, altered Werfen shales and Gröden sandstone

*After a photograph by Dr. C. Diener*

Verona; here, however, the margin of the mountains trends more and more from the east-south-east to the south-east, and we reach far away towards Este the southern extremity of the Euganaean hills. Where, however, does the further continuation of the Alpine border lie? Do Padua and Treviso and the whole Venetian depression, from Vicenza to Görz, actually lie within the Alps?

*Monte Adamello.* We will enter the Alps themselves and visit first the mass of the *Adamello*, composed of granite and tonalite, which rises to the north of Lake Idro on the border of the Tirol and Lombardy, between the valley of Judicaria in the east and Val Camonica in the west. To the east of Cedegolo the granite mass is so constricted between sedimentary formations on both sides, that it would be more correct to speak of two granite regions united by a narrow band. Of these the southern region is the less elevated and less extensive; it includes the Rè di Castello (2,879 meters), Cima di Danerba (2,844 meters), Corno Busecca (2,660 meters), and others; while the northern region comprises the Adamello (3,547 meters), Caré Alto (3,461 meters), the snow fields and glaciers to the north of the Val di Fumo, and as a further continuation the Cima Presanella (3,561 meters) and its neighbourhood.

We have already mentioned that contact phenomena, resembling those of Predazzo, occur in the Trias limestone near the margin of these granitic masses (p. 158).

As early as 1846, J. Trinker, who has added so largely to our knowledge of the Tirol, examined the eastern slopes of this part of the chain, and found that the limestone 'is converted into crystalline structures where it meets the plutonic rocks,' as in the Val de Borguzzo and Val di Daone [1]. He also mentioned the occurrence of garnet in limestone in the latter valley. Not long afterwards Escher, who approached the marginal zone of the granite from the west, described as occurring on the Lago d' Arno, which lies above Cedegolo in a lateral valley of the Val Saviore, a 'band of extremely curious rocks which sometimes bear a strong resemblance to the silicate-formations of the blocks of the Somma in the tuff of Naples, or recall the contact phenomena of Monzoni [2]'. Curioni, Ragazzoni, and Bittner have described some parts of this remarkable marginal zone [3],

[1] J. Trinker, Bericht über die im Sommer 1846 vorgenommene geogn. mont. Reise in Südtirol, in Bericht über die IX. Generalversammlung des Vereines zur geogn. mont. Durchforschung von Tirol und Vorarlberg, 8vo, Innsbruck, 1847, pp. 9, 17.

[2] Escher in B. Studer's Geologie der Schweiz, 1851, I, p. 294.

[3] Curioni has chiefly described the southern part, and in particular the sinus in the tonalite towards Blumone, and the high pass leading into the valley of the Leno, as well as Lago di Campo; the Forcellina pass has been crossed by Ragazzoni: G. Curioni, Ricerche geologiche sull' epoca dell' emersione delle rocce sienitiche (Tonalite) della catena dei Monti dell' Adamello, Mem. Ist. Lomb., 1873, XII, pp. 341–360. The wedges of schist, limestone, and garnet-rock in tonalite, which are described here, are worthy of notice.

but the most detailed accounts have been furnished by Lepsius[1] and Stache[2].

Lepsius has traced the zone of contact in the south-east for a distance of 15 kilometers; he has placed beyond doubt the Triassic age of the limestone beds which are converted into marble, has pointed out the frequent occurrence of garnet, vesuvian, epidote, wollastonite, and other minerals characteristic of igneous contact, and has recognized in the tonalite the source of the transformation. He has nevertheless ascribed an Archaean age to the tonalite, and was led to suppose that it had been passively raised from a depth, 'at which it possessed a temperature of its own, not sufficient to fuse it or to reduce it to a plastic state, but enough to render it capable of producing contact metamorphism[3].'

Stache has traced these marginal alterations for a still greater distance round about the south-east, south, and west border of the mass, where they penetrate in loop-like forms into the mass of tonalite and granite. In his last publication on this subject he points out that the rocks on the western side and far towards the north, which were previously believed to be much older, are really metamorphic products of the Servino, that is, of the lowest part of the Trias. He regards it as certain that in the regions surrounding the Adamello on the east, south, and west, periods of volcanic activity repeatedly occurred during Permian and Trias times; while the numerous intercalations in the marginal zone of dioritic layers resembling flows lead him to the conclusion that these rocks are to be regarded as having been formed under unusual conditions with an 'epicrystalline or even sub-volcanic facies.' At the same time Stache rightly points out that in none of the conglomerates or breccias of any pre-Glacial period, not even in the thick beds of Permian conglomerates which often contain fragments of porphyry, has a pebble of tonalite ever been found.

The relations of the sedimentary beds to the granite and tonalite of Adamello are altogether different from those which may be recognized between Mesozoic deposits and masses of granite or gneiss in other great mountain-cores of the Alps. On the northern margin of the mass of the Finster-Aarhorn Trias and Jurassic deposits lie in long folds (p. 110), in which the oldest beds are above and below, the most recent in the middle. They are folded into the gneiss or granite, and at the

[1] R. Lepsius, Das westliche Südtirol, 4to, Berlin, 1878, particularly pp. 67-77, 148-152, 189, 191-229, 334, 336, &c.; also Verhandl. geol. Reichsanst., 1879, pp. 339-343.

[2] G. Stache, Die Umrandung des Adamellostockes und die Entwicklung der Permformation zwischen Val buona, Giudicaria und Val Camonica, Verhandl. geol. Reichsanst., 1879, pp. 300-310; Aus den Randgebieten des Adamello, op. cit., 1880, pp. 252-255, et passim.

[3] R. Lepsius, Südtirol, p. 76; Doelter's observations in reply in Verhandl. geol. Reichsanst., 1878, pp. 349-351; R. Lepsius, op. cit., 1879, p. 31.

wedge-shaped extremities of the synclinals the well-known alteration of the Jurassic limestone into marble may be perceived. The fissures and thrust planes of the marble may be covered by a green talc-like mineral, the precise nature of which still remains to be determined, but the silicates of igneous contact, such as garnet, epidote, and the rest, have never yet been met with at these loci of maximum mechanical action.

Although the Trias beds of the Adamello penetrate in irregular loops

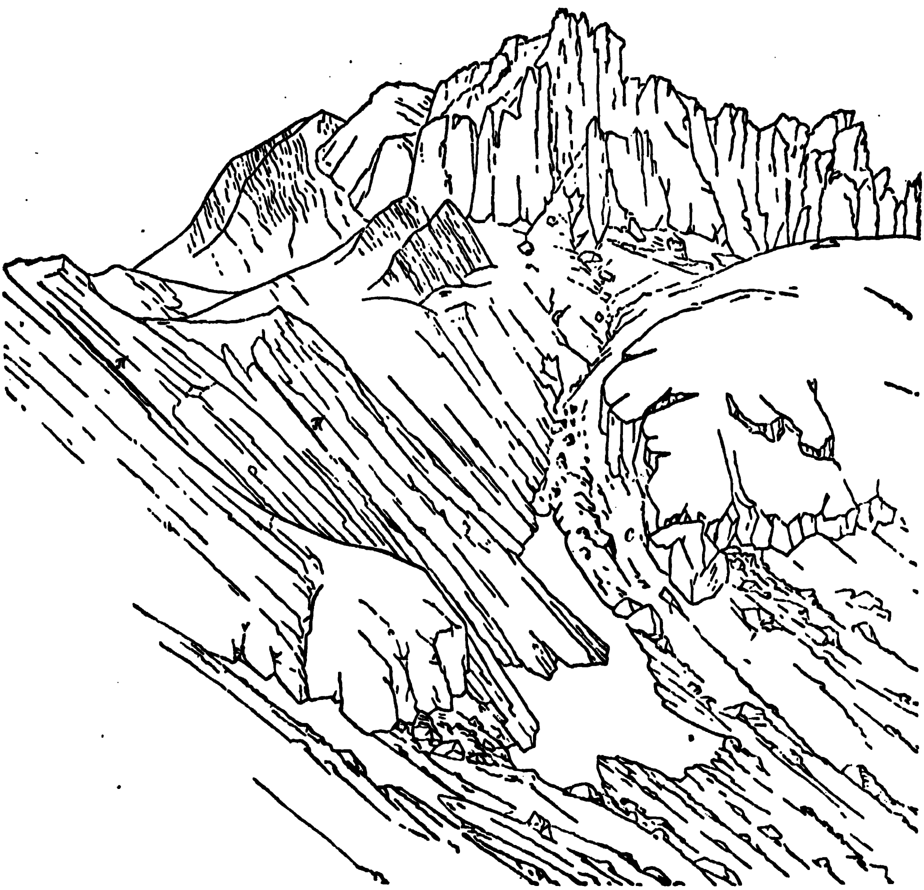


FIG. 27. *Monte Doja.* Mass of the Rè di Castello. The Trias limestone dipping beneath the granite.
c, Line of volcanic contact; $\pi$, $\pi$, sheets of porphyry in Trias limestone.

into the region of tonalite, especially at the point of greatest strangulation to the east of Cedegolo, and although it is only towards the north-east that the junction becomes more rectilinear, yet these Trias beds are not pinched in in wedges like those of the Finster-Aarhorn. In that case it is always the *oldest* sedimentary formations visible in the folds which lie next the granite or gneiss; in this, on the other hand, round about the southern, eastern, and western part, and especially about the southern

part of the Rè di Castello, and at the point of constriction, it is *always the youngest visible member* of the sedimentary formations which lies next the crystalline rock and is metamorphosed for a greater or less distance from the point of contact.

Lepsius has given a very clear description of the manner in which the Trias beds of Monte Doja dip beneath the granite and tonalite masses of the Corno Busecca, at an angle which becomes constantly steeper. The Gröden sandstone, which is visible a great distance away, owing to its red colour, crops out at the Grotta rossa (2,188 meters) in the south, and the Cingolo rosso (2,178 meters) in the south-east; the shales of Werfen cross the Val Aperta, lying between the two summits near the highest Alpine hut, and are followed by the limestone beds of the Trias in Monte Doja, which are visible in thick well-stratified masses more and more steeply inclined, and reaching the point of contact in a ravine in the highest part of the valley[1]. The zone of contact runs close below the summit of Monte Rema (2,372 meters), which rises opposite, and on its southern slopes the line of junction describes a fairly sharp curve, after which it proceeds to the north-north-east. The white marble, at this point particularly rich in crystallized silicates, makes it possible to follow the zone of contact for a great distance.

If, instead of approaching the zone through the Val Aperta, we now do so through the Val di Daone, which succeeds it to the north, we shall reach the boundary of the granite at a distance of 5,500 meters to the north-north-east of Monte Rema, at a level about 1,100 meters lower. The Gröden sandstone exhibits its usual red colour at the lowest part of this long valley, and at the bottom of the valley the Permian porphyry becomes visible beneath it. But at a distance of more than a thousand meters from the zone of contact, this sandstone, which is valued so highly in the smelting works of the Alps on account of its refractory qualities, is already converted into a brownish-grey quartzite; certain beds of lower Trias also pass into the same kind of rock, as is proved by the presence in the latter of sharply defined hollow casts of *Naticella costata*. These quartzite beds, which are of great thickness, form the sides of the valley, while upon them lie the unaltered and richly fossiliferous beds of the Muschelkalk, but far above, where the same beds approach nearer the granite, they are converted into marble. The Gröden sandstone appears to be continued as far as the zone of contact. The contact thus takes place above in the Muschelkalk, and below in the Gröden sandstone.

If we ascend the Val di Daone still further, passing over the zone of

[1] Fig. 27 represents the same place as that of which Lepsius has given a sketch, Südtirol, pp. 73 and 222; Cima Bruffione of Lepsius is the Corno Busecca. For the determination of the tabular form of the intercalations of porphyry I must thank, in particular, Dr. C. Diener, who has climbed the slopes up to the decisive points.

contact and through the area of hard white granite, we enter the region of the greatest constriction of the mountain-core, and reach the western zone of marble above the hut Nudole and to the west of it, towards the lonely Lago di Campo. We are now on the northern slope of the Rè di Castello. White marble, with garnet and other minerals characteristic of contact, occurs with a high dip at the junction with the granite, as in the eastern zone. This marble extends from the Lago d' Arno, where it was observed by Escher, over the frontier pass of the Forcellina (Pl. II) to the Lago di Campo, then turns round in a great curve and passes below the Cima delle Casinelle, as has been described by Stache. The dark-

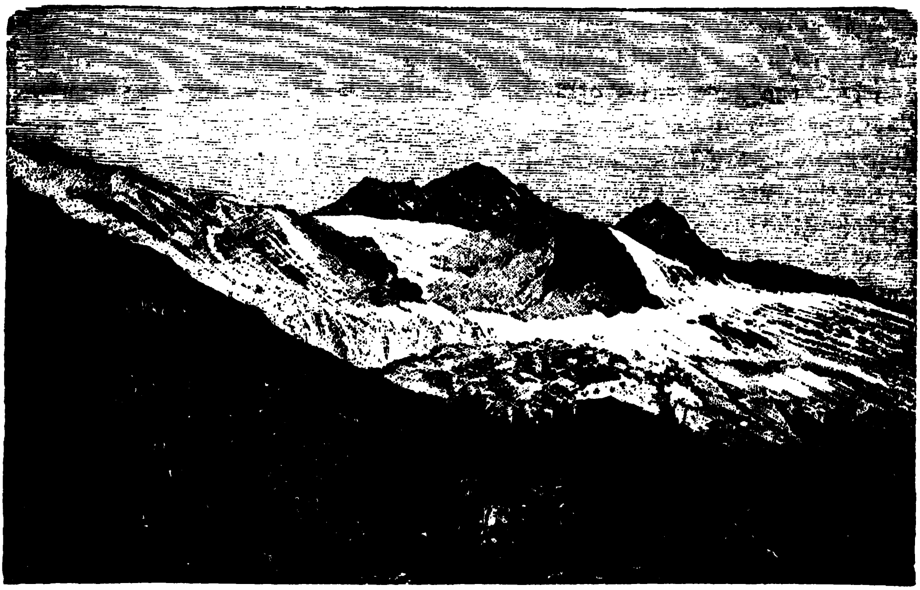


FIG. 28. *Cima delle Casinelle.* (South part of the Adamello mass. Reproduced from a photograph by Dr. C. Diener.)
In the foreground, on the highest peaks and on the right, granitic rocks; on the left the beds of Trias curve down below the snow.

coloured quartzite, which occurs in thick beds within the zone of marble, is identical with the altered Gröden sandstone of the lower Val di Daone. True spotted schists appear at about the horizon of the Werfen shales.

As far as our knowledge of the southern half of the margin of the Adamello region extends, the sedimentary rocks dip from all sides beneath the granite and tonalite like a funnel, or they break off with flexed edges in a steep fracture: the youngest beds occur next the contact, the older lie successively further away from it. This furnishes an explanation of the encompassing zone of marble. No other great granite mass of the Alps presents a similar structure; no other shows the silicates of igneous

contact. The smaller masses of Predazzo and Monzoni are the only others which present similar characters.

Adamello and its southern segment, the Rè di Castello, has, in common with Predazzo and Monzoni, a well-defined massive core and a surrounding belt of marble containing the silicates of contact. The age of the altered rocks is probably nearly the same in all three cases, that is to say, a little more recent than the Muschelkalk. The two regions, however, differ in so far as the dykes and flows of melaphyre together with the accompanying tuffs, which surround the eruptive centres of Predazzo and Monzoni, are entirely absent in the neighbourhood of the Adamello. To the east of this mass, to the south, and also in the north, towards the Ortler, as well as to the west, in the Mesozoic folds which traverse the Bernina, the upper members of the Trias are known to occur; and to the south and east the long series of younger sediments also occurs; but the vast sheets of lavas or ash, which would naturally be associated with such an important centre of eruption, are nowhere present.

In the aureole of contact, 500 to 2,000 meters in width, a great diversity of intercalated igneous rocks is certainly not wanting. Among these, three groups may be easily distinguished. The first includes the sheets of brownish-red porphyry ($\pi$, $\pi$, Fig. 27), which are normally intercalated with the beds of the Trias; I believe that they correspond to the outpoured sheets of Trias porphyry which may be seen at so many places in the southern Alps, from the Luschariberg, near Raibl, to the Val Trompia, and even further west. The second group comprises three masses which fill the fissures in the brown quartzite of the Gröden sandstone. The infilling material consists of large crystals of white orthoclase, large flakes of white mica and sheaves of tourmaline in grey quartz, also of coarse-grained granite, such as occurs in the dykes of so many granite regions; here, these veins, which present all the characters of segregation veins, extend, as we have said, into the Gröden sandstone. The third group finally is formed of true intrusive veins; the few I have seen consist of a decomposed green rock with crystals of white feldspar; one of these veins may be seen below the Passo della Forcellina intersecting obliquely the banded limestone beds, with which it is in close contact. In those parts of the western border which have been investigated by Stache, the intrusions appear to be more numerous and considerable.

The zone of volcanic contact which surrounds the whole group of the Rè di Castello and a large part of the Adamello compels us to consider this great complex of granite and tonalite as a volcanic formation, which must be of more recent origin than the upper Muschelkalk. Opinions may differ as to whether it is to be considered as a cicatrice or a laccolite, i.e. whether the volcanic mass actually produced an eruption at the

surface or not. To elucidate this question let us first follow the complex in its further course to the north-north-east.

*The Judicarian line.* The eastern boundary of the tonalite region proceeds in a straight line to the north-north-east. Stache, who has traced it, did not meet with the zone of marble again in the Val di Breguzzo or in the valleys succeeding it to the north, but he observed gneissose phyllites which however also dip towards the west beneath the tonalite. The direction of the main axis of the whole complex to north-north-east and the course of its faulted boundary reveal the existence of a close connexion between the tonalite mass and the great easterly line of dislocation of the Judicaria, which passes close to it and runs in nearly the same direction.

If we turn from Lake Idro to the north and enter the valley of the Upper Chiese (the Judicaria), we shall see on the left thick dark masses of Permian porphyry, tuff, shales and sandstone, on the right the white limestone walls of the upper Trias. The downthrow of the beds to the right may amount to at least 2,000 meters. This is the mighty fracture along which the subsidence begins of all the region lying to the east, in the direction of the Adige. The same contrast between the two sides of the valley may also be observed near Storo. About nine kilometers higher up the valley, which runs in a straight line to north-north-east, at the entrance to the Val di Daone, the fracture has passed into a great flexure. The same beds of Muschelkalk, which further to the west dip beneath the granite as white marble charged with garnet and epidote, appear here as dark highly fossiliferous limestones, which incline eastwards towards the valley in great broken curves, and dip beneath the almost horizontal beds of upper Trias which form the eastern side of the Judicaria [1].

The disturbance soon regains the character of a fault. Where the valley of the Judicaria bends to the north-east it retains its direction to the north-north-east and proceeds, as Bittner has shown, through the mountains, from Roncone to Verdesina, and so reaches the Val Rendena; this valley it follows as far as Pinzolo; there it again enters the mountains without any change of direction, traverses them and crosses near Malé, at the entrance to the valley of the Rabbi, the great Val di Sole. From here it is gradually deflected from the north-north-east, somewhat to the north-east, and proceeds from Malé through Bevia towards Mocenigo and reaches the valley of the Etsch south of the entrance to the valley of Ulten [2].

[1] This exposure, which is very clear and instructive, has lately been described in detail by Bittner, Ueber die geol. Aufnahmen in Judicarien und Val Sabbia; Jahrb. der geol. Reichsanst., 1881, XXXI, p. 219 et seq.

[2] G. Stache, Verhandl. der geol. Reichsanst., 1879, pp. 127, 250.

This line, which will be found to be of the highest importance in the ensuing investigation, has a length of about thirty-four kilometers from Lake Idro to the point where it reaches the Val Rendena, near Verdesina; thence as far as the Val di Sole near Malé of thirty-six kilometers, and from Malé as far as the valley of the Adige, below Lana, of thirty-two kilometers, or altogether for this part of its course 102 kilometers. The eastern side of the fault is formed by the down-sunken Mesozoic formations of the valley of the Etsch, which however, in the neighbourhood of the fault, frequently appear to be inclined downwards towards it. At the imposing Laugenspitze, to the south of the point where the fault crosses the valley of the Etsch, it is the Permian porphyry which appears as the base of the Mesozoic limestones on the eastern side of the fault.

The west side consists in the south, towards the Rè di Castello and the Adamello, first of those bands of Permian and Trias rocks which we have just studied on the east border of the mass of the Adamello. The east border of the Presanella, in which a rock appears, which is described as tonalite gneiss, is, according to Stache, only separated from the line of the Judicaria by a narrow zone of ancient phyllites. Further to the north, gneiss and phyllite form the greater part of the western border, until isolated bosses of tonalite and younger granite again appear. Finally, before reaching the valley of the Etsch, another great mass of tonalite arises on the west side of the fracture, and extends from St. Pankraz in the lower Ulten up to the Etsch. Here, porphyry and Gröden sandstone form, as already mentioned, the east side of the fault.

The map of the district around Meran, published by C. W. C. Fuchs, shows clearly how the tonalite boss, the great fault, with the porphyries and Permian beds of its east side cross the valley of the Etsch obliquely near this town [1]. The further continuation of the fault has been determined by the valuable investigations of Teller. The Judicarian fracture may be followed through the gorge of the Naif, near Meran, as far as Weissenbach in the valley of the Pens; from here its course turns more and more from the north-east to the east. This last segment is twenty-six kilometers in length, so that the whole length of the fault, from Lake Idro to the valley of the Pens, measures about 128 kilometers. The most remarkable result of Teller's researches is however the proof that the granite mass is continued a long way to the east. The Iffinger above Meran (2,551 meters), already recognized by Fuchs as the continuation of the tonalite mass which rises on the other side of the Etsch, is only a part of a very long band, the principal mass of which consists of granite, but on its northern side it is composed of a continuous zone of tonalite gneiss. This chain strikes through the valley of the Pens, then to the

[1] C. W. C. Fuchs, Die Umgebung von Meran; Neu. Jahrb. f. Min., 1875, pp. 812-848, pl. xvi.

east, near Mauls and Franzensfeste, and across the Brenner route[1]. Near the latter, where the band of granite attains its greatest breadth, the fault of the Judicaria is no longer visible on its south side, and the granite band itself lies to the north and south like an arch below the bordering zones of rock. After following the valley of the Puster nearly as far as

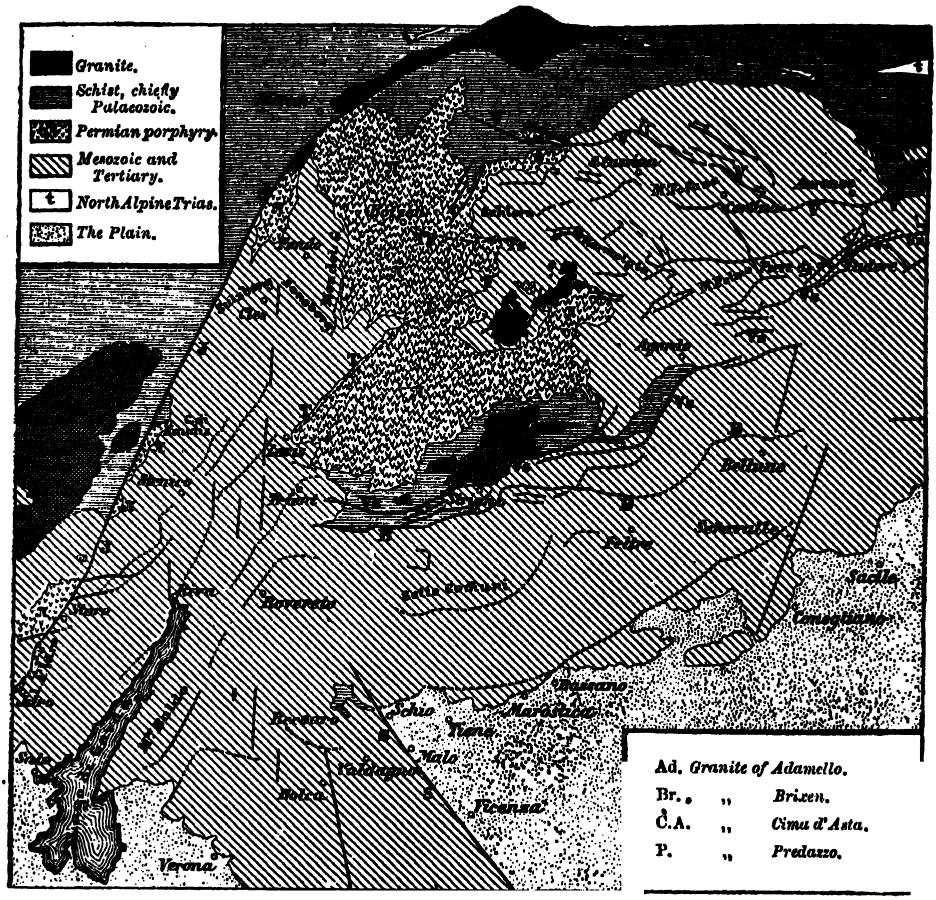



FIG. 29. *Approximate arrangement of the principal fractures and flexures which surround the Cima d' Asta.*

*J* Line of the Judicaria; *Vs* line of the Val Sugana; *B* line of Belluno; *S* line of Schio; *T* line of Truden; *Ts* line of Tiers; *V* line of Villnöss.

Brunneck, the granite band dips out of sight and seems to have reached its termination, but from beneath the gneiss and gneissose phyllites in

[1] F. Teller, Ueber die Aufnahmen im unteren Vintschgau und im Iffinger-Gebiete bei Meran, Verhandl. der geol. Reichsanst., 1878, pp. 392-396; Aufnahmen zwischen Etsch und Eisack, op. cit., 1880, pp. 91-98; Tektonik der Brixener Granitmasse und ihrer nördlichen Umrandung, op. cit., 1881, pp. 69-74; Aufnahme im Hochpusterthale, op. cit., 1882, pp. 342-346; cf. also Pichler, Beiträge zur Geognosie von Tirol, Neu. Jahrb. f. Min., 1871, pp. 256 et seq.

the Antholzer mountains (Schnebiger Nock, 3,390 meters), on the other side of the valley of the Ahr, north of Brunneck, another dome of granite, surrounded by a ring of tonalite gneiss, makes its appearance. Teller thinks that it stands in intimate connexion with the surrounding gneissose phyllites; these contain numerous small lenticular intercalations of the granite, while towards the south-west a subsidiary lenticular mass attains such an exceptional size, that it crosses the ridges separating three not inconsiderable valleys in an elongated band[1].

We thus see a very great line of fracture, stretching from Lake Idro through Judicaria, through Val Rendena, past Malé, through the gorge of the Naif, near Meran, as far as the valley of the Pens, for a distance of about 128 kilometers; after maintaining a direct course to the north-north-east nearly as far as Meran, it then turns round in a hook-like curve to the north-east. Along its whole length we see the country thrown down on its eastern side. Further, we see to the west of the Judicaria, elongated in the direction of the fault, the great mass of tonalite and granite which embraces the Rè di Castello, Adamello, and Presanella; where it comes in contact with the Trias limestones in the south it overlies them at the margin, and alters them as by volcanic contact. Further to the north a second great zone of granite emerges, accompanied by tonalite gneiss on its north side only; on the south side it is situated close to the bent end of the great fault, the curve of which it follows, its strike gradually passing from north-north-east to north-east and finally to due east. At its extremity it is accompanied by the mass of Antholz, which is intimately connected with the gneiss by numerous intercalations. The question asked above now assumes the following form: whether the two granite masses, which are distinguished by the associated presence of tonalite, and by their relations to the great fault, are of quite distinct age, or whether they are a series of contemporaneous laccolites, which at one end of the fault have altered the Trias beds in the Rè di Castello, and at the other are exposed in the mass of Antholz at the far lower horizon of the gneiss region.

In the region between the Eisack and the Etsch, where the curvature in the direction of the fault and the granite band takes place, a remarkable tectonic phenomenon appears, the existence of which Teller has also recognized. The country lying to the north of the fault is thrust over the granite band; it consists of gneiss, mica-schist, phyllite, Verrucano and Trias limestone containing Diplopora. As we ascend from Sterzing on the Brenner road to the Penserjoch on the south, we see, below the Seilspitz, the gently dipping thrust plane along which the phyllites, probably of Carboniferous age, are driven over the Trias limestone (Fig. 30). In the lower parts of the wedge of limestone the beds stand erect as

[1] Teller, Verhandl. geol. Reichsanst., 1882, p. 345.

though resisting the force exerted upon them by the mass of older phyllites (Fig. 31). We observe that this great wedge is directed upwards and outwards, and not, as generally occurs in the mass of the Finster-Aarhorn, into the interior of the chain. The layers of gneiss, which lie below the limestone, contain, at the summit of the ridge, bands of Verrucano conglomerate, which have been kneaded into them. To the south of the ridge lie ancient schists; and here traces are to be seen of another band of limestone, which appears to pass through them; a small fahlerz mine is situated on the lower part of the slope, and the tonalite begins to appear in the valley bottom, near Asten[1].

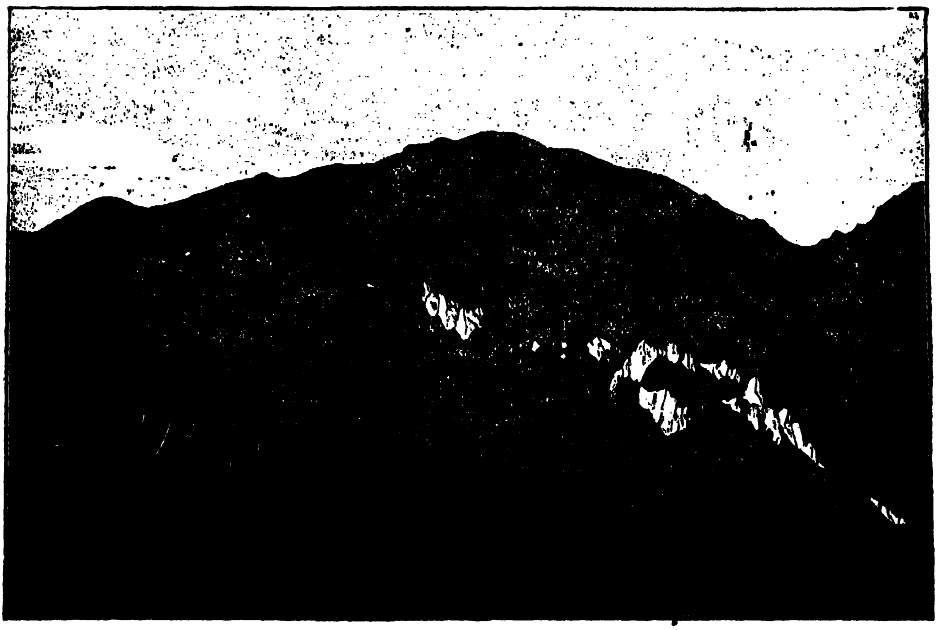


FIG. 30. *Seilspitz, ascent to the Penserjoch* (west of the Brenner road). Long wedge of Trias limestone in phyllite.

*The faults of the Cima d' Asta.* The line of Judicaria, with the bands of granite and tonalite accompanying it, forms on the west and north-west the enclosing border or 'frame' of an extensive area of subsidence—the basin of the Adriatic Sea—which is bounded on the east and south-east by the flexures and faults of the Karst and of the Dalmatian coast. It is only in the last few years that the connexion between the various phenomena of this region has gradually become clear. In 1875 I could only speak of isolated, apparently exceptional overthrusts to the

[1] Here I found great blocks of pale yellow hornstone, such as I have not seen anywhere else in the Alps; it is possible that they have been derived from the contact of tonalite and schist.

south on the Cima d' Asta near Sant' Orso not far from Schio, and along certain faults in the Karst; whereas to-day subsidence, and frequently overthrusting also, are recognized as the rule over the whole of this large area, under circumstances which are, it is true, peculiar and essentially different from those which may be observed in the northern Alps.

The greatest progress achieved here must be ascribed to the admirable manner in which Edmund von Mojsisovics and his fellow workers have conducted their researches in the southern Tyrol and the mountains of the adjacent parts of Italy. A large part of the west of this region has been found to be traversed by a network of faults, the disposition of which has been exactly determined. As early as 1879 Mojsisovics was

FIG. 31. *Trias limestone overthrust by phyllite, in the limestone wedge of the Seilspitz.*

able to publish a general account of the fault-lines between the Etsch and the Piave, which has been completed and extended in all directions by the subsequent researches of Austrian and Italian geologists[1].

In the year 1882 T. Taramelli represented on a sketch-map the most important lines of dislocation in the district extending from Lake Garda to Istria[2]. As I have personally investigated a large part of this area I will here attempt to give a fresh survey of the results so far obtained, and I propose at the same time to enter into certain details, which appear to me

[1] E. Mojsisovics v. Mojsvár, Die Dolomitriffe von Südtirol und Venetien, 8vo, 1879, pp. 106, 515, 518, &c.

[2] T. Taramelli, Geologia delle provincie Venete; Mem. Accad. Lincei, 1882, XIII, pl. ii.

of importance, in relation to the question of the structure and origin of great mountain chains in general.

I would first recall the tabular faults of Utah (p. 129, Fig. 13), which start from the western margin of the Wahsatch, especially as regards their fascicular arrangement, the variation in the amount of their throw, and the relations existing between them and the flexures of the same district. It is impossible to read the description given by Mojsisovics of the great faults of the southern Alps without being struck by a remarkable correspondence between many of their features and those of the faults of Utah. The fan-like splitting up of some of the faults, the intermittency of the less important fault-lines, the replacement of a single great dislocation by a parallel splintering, the transference of a maximum throw from one dislocation to another—all these phenomena, observed by Mojsisovics in the faults of South Tyrol, are repeated in the fractured areas of West America. A difference nevertheless exists between the two regions, in so far as the faults of the southern Alps were accompanied by tangential movements (producing flaws and overthrusts), which as we shall see presently were directed from the margin of the sunken area towards its centre.

To the north of the Brenta rises the extensive granite mass of the Cima d' Asta. It does not, like the phyllite of Recoaro, lie in the bottom of an eroded valley, but rises as a lofty independent mass isolated among the limestone Alps, on the southern border of the great porphyry region. It forms one of the most striking features in the structure of the southern Alps. 'Here I no longer understand man and I hardly understand nature,' wrote the great pioneer Leopold von Buch, when he arrived at Pergine in 1798. 'The various rocks seem to be tumbled together chaotically and the beautiful order of the Brenner has wholly disappeared. Who would have thought of again finding primitive rocks, after such tremendous masses of limestone as the terrible chain between Neumarkt and Trento, after mountains such as those which surround Trento? . . . With painful regret I saw a structure collapse which gave us the history and at the same time the system, and led us insensibly, as we followed the succession of stratified systems from our present world to an earlier one, the existence of which we had at first suspected without understanding, to believe later that we were approaching its comprehension [1].'

The southern margin of the Cima d' Asta is a vast trough-fault, the northern side, though composed of granite, standing far higher than

[1] L. v. Buch, Ueber die geognostische Beschaffenheit der Gegend von Pergine, Der Gesellsch. naturf. Freunde zu Berlin neue Schriften, 1801, III, p. 233; also in the Geognostische Beobachtungen auf Reisen, 1802, and in the complete edition of his works published by Ewald, Roth und Eck, 1867, I, p. 328; also G. v. Rath, Die Lagoraikette und das Cima d'Astagebirge, Jahrb. geol. Reichsanst., 1863, XIII, pp. 121–128.

the southern, to which the great Trias walls of the Cima Dodeci and the Sette Communi belong. At the bottom of the trough, traversed by a whole network of subsidiary fissures, lies the porphyry mountain of Zaccon, followed by great mountains of Trias limestone, such as Monte Armentera and Monte Civeron, which have been faulted down from the mass of the Sette Communi, and finally, beds of Tertiary, Cretaceous, and Jurassic age, superposed on each other in inverse order, and overthrust from the north by the granite and phyllite of the Cima d' Asta [1].

Towards the west these faults diminish rapidly in importance and do not reach the valley of the Etsch [2]. On the other hand they extend to the north-east and east. Mojsisovics has named the chief of these faults, which is also the most northerly, the *line of the Val Sugana*. It is along

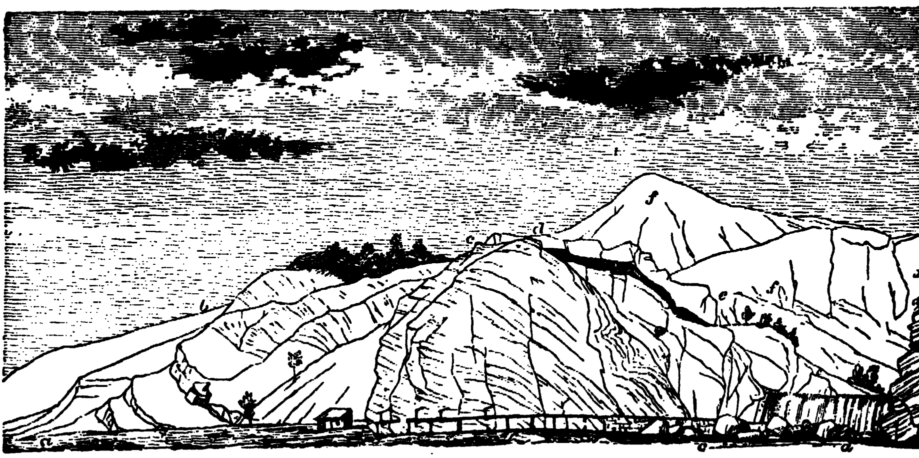



FIG. 32. *Entrance to the gorge of Torrente Maso, south side of the Cima d' Asta.*
Reversed series :—*a–b* alternating beds of clay and Nummulitic limestone ; *b–c* Scaglia and Biancone ; *c–d* Diphya limestone, Acanthicus zone, dark red bed rich in hornstone, white Jurassic limestone (lower Oolite?) ; *e, e* phyllite ; *f, f* granite.

this line that the granite and phyllite are cut off and overthrust; it constitutes as it were the southern front of the Cima d' Asta, which recalls, in its relation to the sheaf of fractures, the position of the western front of the Wahsatch to the fractures of the Sevier.

The line of the Val Sugana runs, together with its subordinate ramifications and transitions, towards the north-east, and crosses the Cordevole to the south of Agordo, the Pieve to the north of Longarone. Still further to the north-east it approaches, as has been shown by

[1] I have described this locality in Ueber die Aequivalente des Rothliegenden in den Südalpen, Sitzungsber. k. Akad. Wiss. Wien, 1868, LVII, p. 230 et seq., pl. i; also Entstehung der Alpen, pp. 86-89. See also Mojsisovics, Dolomitriffe, in particular p. 417.

[2] This western region has been described by W. Gümbel in Geognostische Mittheilungen aus den Alpen, III; Sitzungsber. Akad. München, 1876, VI, p. 61 et seq.

Harada, the group of the Villnöss faults, which come from the west-north-west, and which will be discussed later. In this way are formed those complicated fields of fracture, which run from Pieve di Cadore towards Rigolato and correspond to the more southern faults of the neighbourhood of Cortino d' Ampezzo and to the flexure of the Upper Tagliamento [1]. The north-eastern direction predominates here also, but its further continuation in the Carnic Alps has not yet been clearly demonstrated.

The distance from the point where the line of the Val Sugana originates, south of Trient, to the shattered region of Rigolato amounts to nearly 140 kilometers. The extraordinary local variation in the thickness of the Permian porphyry sheets, and of the limestone masses of the Trias as well, renders it difficult to determine exactly the extent of the vertical dislocation, but along the southern front of the Cima d' Asta it must be far more than 2,000 meters, possibly even more than 3,000 meters. Everywhere along this main line it is the southern side which is thrown down, and this is the rule for the whole group of dislocations of the Cima d' Asta, so that the total amount of the successive subsidences sums itself up towards the south.

The second important line of this group has been named by Mojsisovics the *line of Belluno.* It branches off from the line of the Val Sugana near the origin of the latter, is separated from it in the Val Sugana by the subsidiary line of Monte Zaccon, and runs to the east-south-east north of Feltre as far as the district north of Belluno, assuming, as Hoernes has shown, the form of a flexure in the whole of its eastern part. Near Belluno it meets the transverse line of Santa Croce, which is directed to the north. The great mass of Monte Cavallo, projecting from north to south, does not seem, according to existing data, to be traversed by the flexure, but, according to Taramelli's description, there begins near Barcis, in Val Zelline, on the eastern slope of Monte Cavallo, a new line of subsidence of great length, running with a gentle curve to the north-north-east; this, Taramelli thinks, must be considered as the continuation of the line of Belluno. It crosses the Tagliamento near Gemona, and reaches the region of the Isonzo at Starasella, not far from Caporetto [2].

This line, which for the greater part of its course from Barcis past Gemona towards the Isonzo forms the boundary between the higher-lying Trias mountains and the sunken Cretaceous and Tertiary mountains which now lie to the south, has been named by Taramelli the *Frattura periadriatica,* a designation which may be applied to all the faults of this extensive field of fracture as far as Meran, Lienz, and Idria.

[1] Toyokitsi Harada, Ein Beitrag zur Geologie des Comelico und der westlichen Carnia; Jahrb. geol. Reichsanst., 1883, XXXIII, pp. 151-188, pl. i, ii.

[2] T. Taramelli, Spiegazione della carta geologica del Friuli, 12mo, Pavia, 1881, p. 172, and Geol. delle prov. Venete (Mem. Accad. Lincei, XIII, 1882), p. 201, pl. ii.

Before this line reaches Starasella it enters for a short distance the region of Trias and Rhaetic limestones, separating the mass of Monte Matajur from the chief region of the Trias limestones, but near Caporetto it almost immediately meets again the fractured region, recognized by Stur in 1858, on the southern edge of the great limestone mountains lying to the east of the Isonzo. In this locality, between Monte Canin and the Natisone, Stur distinguishes three fractures with overthrust from the north, by which the Rhaetic limestone is carried over the Cretaceous. This is the district in which the group of the Karst faults appears, which will be discussed later[1].

The line of Belluno measures not less than 180–190 kilometers from its origin to the Isonzo, i. e. if we include, with Taramelli, the segment lying on the other side of Monte Cavallo; and even to the east of Caporetto, towards Deutschruth, the boundary of the Cretaceous lies in its further continuation. But the connexion between these segments has not yet been established.


FIG. 33. *The Torrente Silano (Val Rovina) entering the plain (west of the Brenta).*

The first hill on the left, which rises on the edge of the plain, consists of marine deposits of an older Mediterranean stage; then follow the Schio beds steeply inclined to the plain; then basalt (drawn dark)—this includes the pointed summit of Monte Gloso; now follows a thick series of coral limestone, also tuff with *Natica crassatina*, all belonging to the stage of Castel' Gomberto nearly up to the little church of San Michele (*a*). Near San Michele the second band of Schio beds begins; this is again followed by the stage of Castel' Gomberto, then by the marls of Laverda, erect and overfolded by lower Tertiary and Cretaceous.

To the south of the western half of the line of Belluno the country continues to sink in a series of great flexures, which however have no direct connexion with the group of faults of the Cima d' Asta. One of these flexures traverses the Sette Communi, its course forming a curve with its convex side towards the south. The limestone mountains to the south of the Cima d' Asta form, according to Vacek's observations, a kind of cupola, with the north-western side (Monte Dosso) faulted down. The strata then dip a little to the south, rise again, and finally fall away in a great flexure which runs north of Primolano, first to the east and then to the north-east.

A second and much longer flexure is overfolded to the south at its origin near Sant' Orso to the east of Schio; it then passes to the north-east,

[1] D. Stur, Das Isonzothal von Flitsch abwärts bis Görz, &c.; Jahrb. geol. Reichsanst., 1858, IX, pp. 365, 366.

past Bassano towards Serravalle, forming the outer edge of the chain towards the plain, and accompanied in places by a parallel fault, which gives rise to a repetition of the Tertiary series in the outer border (Fig. 33)[1].

From these observations it would appear that the southern Alps, from the Lake of Caldonazzo, south of Trient past the south front of the Cima d' Asta to Agordo, Pieve di Cadore, and Rigolato, and south of this north-easterly line to the plain, present a structure which resembles a great flight of stairs facing south, its steps increasing in breadth and number towards the east, while diminishing in height. Some of the highest of these steps approach the trough on the south side of the Cima d' Asta. The steps lying nearest to the plain have the form of flexures, those more to the north correspond almost exclusively to faults.

*The region between the Judicarian fault and the fault of the Schio.* From the north-western part of the field of fracture rises the irregular contours of that great buckler of Permian porphyry, in the depression of which the Etsch and the Eisack unite near Bozen ($\pi$, $\pi$, Fig. 29). Towards the south and north older deposits crop out from beneath the porphyry; towards the east and west the porphyry dips down beneath younger deposits. To the south the micaceous slate and the granite of the Cima d' Asta crop out; their fractured border running to the south has already been discussed. To the north the micaceous slate again crops out. The younger formations which overlie the porphyry to the east form that part of the Tyrol, so famous for the beauty of its scenery, which is somewhat erroneously termed the 'Dolomite region.' The western dips more steeply than the eastern border, and assumes in places the form of a flexure overfolded to the west. It passes beneath a long narrow zone of deposits, which comprises the whole series of strata from the Permian up to the middle Tertiary, and is thrown down in a great trough between the flexure of the western margin of the porphyry and the line of the Judicaria.

This narrow zone has received the name of the inset mountains of the Etsch (Etschbuchtgebirge); it comprises the broad Nonsberg, the wild mountains of the Brenta with the Cima Tosa, several peaks of which rise to an elevation of over 3,000 meters, and a number of other important heights, characterized by a more or less marked strike to the north-east. This direction is particularly noticeable to the south, where the line of the Judicaria and the margin of the porphyry buckler diverge from each other. Still further to the south the zone steadily increases in

[1] M. Vacek, Die Sette Communi, Verhandl. geol. Reichsanst., 1877, pp. 211–213 and 301–305; Bittner, Die Tertiärbildungen von Bassano und Schio, tom. cit., pp. 207–210, and Das Tertiär von Marostica, op. cit., 1878, pp. 127–130.

breadth, the trough subsidence terminates, and the prolongation of the inset mountains of the Etsch then includes both shores of Lake Garda and all the mountains and foot-hills far and wide up to the *fault-line of the Schio.*

We return to the northern part.

The porphyry surrounds the northern end of the zone and extends, as we have already seen, along the line of the Judicaria some way beyond the Laugenspitze; still older schists, here and there granite also, crop out owing to an upward flexure of the beds along the line of the Judicaria; in the Val Rendena the porphyry in turn is flexed upwards and for a greater distance, so that it is visible on both sides of the trough.

The structure of the inset mountains of the Etsch has been made the subject of investigation by Vacek and Bittner[1]. The following are the most important features:—

The trough is not symmetrical. On its eastern side a single flexure, dropped and somewhat overfolded to the west, occurs on the edge of the porphyry, while the country lying between this flexure and the line of the Judicaria is traversed by a large number of flexures, which are dropped and overfolded to the east or south-east in the direction of the line of the Judicaria. I describe these lines of disturbance as flexures, and apply the same term to those lying south of the fractures of the Cima d' Asta, although they are all distinguished from the simple type of step-like flexure by two characteristics, namely, that the upper limb is inverted or overfolded, and that the lower limb possesses a slight inclination in the opposite direction. This gives these disturbances the appearance of very superficial oblique folds, but it is evident that every flexure must undergo this modification whenever subsidence is accompanied by horizontal movement directed towards the subsiding area.

These flexures strike, as we have said, more or less parallel to the line of the Judicaria, and are dropped in the same direction with overfolding of the upper limb, that is, in the opposite direction to the margin of the porphyry buckler. They extend through the whole of the inset mountains of the Etsch, and down both sides of Lake Garda. Complications arise towards the south-west owing to interference by lines of disturbance which proceed in an east-south-east to east-north-east direction from the sunken area of Lombardy; one of the most important of these disturbances comes from the Val Trompia near Ponte di Caffaro to the line of the Judicaria, and appears to cross it. The entrance of the Lombardic flexures and fissures into this region may be clearly seen

[1] M. Vacek, Die Umgebungen von Roveredo, Verhandl. geol. Reichsanst., 1878, pp. 341-345; Umgebungen von Trient, op. cit., 1881, pp. 157-162; Nonsberg, op. cit., 1882, pp. 42-46; A. Bittner, Sedimentgebilde in Judicarien, op. cit., 1880, pp. 233-238; the same in Jahrb. geol. Reichsanst., 1881, XXXI, p. 359 et seq., and elsewhere.

in the veins of Barghe in Val Sabbia, described by Edmund Fuchs, and in many other places [1].

On the east side of Lake Garda the flexures of the Judicaria are still met with in their typical form. One of these oblique flexures forms, as Bittner and Nicolis have shown, the ridge of Monte Baldo. On the eastern shore of the lake isolated patches of Tertiary beds may be seen resting on the Cretaceous; then the strata ascend gradually towards the east, until they terminate partly in a sharp flexure, partly in a fault, in such a way that the Tertiary beds are bent upwards against the Trias or break off abruptly against it [2].

It is along this line on the east side of Monte Baldo that the much-discussed seismic phenomena of this chain appear to occur [3]. On the other side of the Etsch, a corresponding disturbance parallel to the line of Monte Baldo occurs on the eastern side of Monte Pastello and Pastelletto. Thus far extends the region of the flexures of the Judicaria.

To Vacek belongs the credit of having shown that some of these flexures, chiefly in the neighbourhood of the valley of the Etsch, swerve round in an arc and with a completely altered strike proceed towards the east, where they merge into the flexures which run parallel to the faults of the Asta. I attach great importance to this phenomenon, since it reveals the connexion between different movements; we shall meet with it again on a much larger scale in India [4]. In the south

[1] E. Fuchs, Étude sur les gisements métallifères des vallées Trompia, Sabbia et Sassina; Ann. d. Mines, 1868, 6e sér., XIII, p. 420, pl. xvi, fig. 7. I am not sure whether the veins of the Val Trompia, which have been described by E. Fuchs, and subsequently by myself, are to be included among the flexures of the Judicaria, or among the faults running north to south which will be discussed directly: Ueber das Rothliegende im Val Trompia, Sitzungsber. k. Akad. Wiss. Wien, 1869, LIX, p. 107 et seq. The great complexity of structure in this locality has been recently described by Bittner in his Nachträge zum Berichte über die geolog. Aufnahmen in Judicarien und Val Sabbia; Jahrb. geol. Reichsanst., 1883, XXXIII, p. 438 et seq.

[2] The south part of the line of the Baldo certainly turns from the strike of the Judicaria towards the west, while subsidence and overturning take place towards the south: Bittner, Der geologische Bau des südlichen Baldogebirges, Verhandl. geol. Reichsanst., 1879, pp. 396–402, and E. Nicolis, Note illustrative alla carta geologica della provincia di Verona, 8vo, Verona, 1882, pp. 118–122.

[3] This at least would result from Goiran's indications; cf. his Meteorologia endogena, 12mo, Verona, 1879, p. 22 et seq.

[4] It must first be observed that it is to the east and south-east of Trient, in the direction of Pergine and the Lago di Caldonazzo, that the extremities of the great fractures of the Asta lie. As far as this, micaceous slate is visible between the fractures, and the termination of the fractures appears to coincide with a local wedging out of the porphyry sheets (Fig. 29). Here, according to Vacek, the bending round of the first flexure across the Etsch takes place in such a way that this flexure, approaching from the south-west from Orto d' Abramo, assumes an easterly direction immediately to the north of Trient, that is to the north of the termination of the fractures of the Asta, and at the same time it becomes twisted. For while at Orto d' Abramo the direction of the Judicaria is

the line of Pastello appears to curve round in the same manner, and to find its continuation in a flexure which, starting from the southern slopes of the Corno d' Aquiglio, defines the southern border of the Monti Lessini [1].

From the valley of the Etsch as far as Schio several flexures are present, having as a rule a line of strike slightly convex to the south; their southern limb is dropped and the northern limb sometimes thrust over it. One of the most important of these flexures passes to the south of the caldron of Recoaro and defines the boundary between the Trias mountains and the less elevated ridges of Cretaceous and Tertiary beds [2].

We must now retrace our steps once more northwards into the inset mountains of the Etsch, that we may become acquainted with a series of disturbances which differ from the flexures.

All later observers agree as to the fact that, north of the Nonsberg, some sharply defined fractures occur with a throw to the east, and that these cut the flexures (or inclined folds) at an acute angle, and run from north to south. Between Trient and Riva three or four of these fractures are met with. They recur south of Val Ronchi and towards Velo with the same north to south strike; one large fracture with downthrow on the east, but with a strike more towards the north-north-west, has been traced by Bittner from the neighbourhood of Montecchià past Bolca to Monte Spitz; it forms the western boundary of the chief area of Tertiary deposits of the Vicentin, and, as Bittner justly remarks, this fissure, by reason of its direction, indicates a fan-like arrangement, the last branch of which is the great fault of Schio [3].

This great fault begins in the high mountains north-west of Schio, and forms as far as the neighbourhood of that town the western border of the tremendous flexure overfolded near Sant' Orso to the south, which

normally accompanied by downthrow on the east side, over which the western side is shoved, that part of the flexure which lies north of Trient, and which strikes to the east, shows the north side downthrown and the south driven over it. A second flexure strikes in the same direction as that of Orto d' Abramo from Monte Bastornata, north of Rovereto to the Etsch, and crosses the valley with a similar bending near Calliano, that is to say, south of the fractures of the Asta, and this is not twisted, but the same wing remains depressed; thus at Monte Bastornata the east side is downthrown, beyond Calliano the south side. Opposite the northern flexure (Orto d' Abramo—St. Agatha north of Trient) a flexure occurs on Monte Kalis between St. Agatha and the porphyry, which is overturned to the south-south-west, as though a small trough subsidence passed between the termination of the faults of the Asta and the porphyry mass of Lavis: Vacek, Verhandl. geol. Reichsanst., 1881, p. 161.

[1] Vacek in Bittner, V. Sabbia; Jahrb. geol. Reichsanst., 1881, XXXI, p. 365.

[2] Bittner, Das Alpengebiet zwischen Vicenza und Verona; Verhandl. geol. Reichsanst., 1877, pp. 226-231.

[3] By the same, Vorlage der Karte der Tredici Communi; op. cit., 1878, pp. 59-63.

causes the mountains of the Tretto to sink beneath the plain of Thiene. From Schio onwards, however, it marks the boundary which separates the Scaglia and the Tertiary formations from the plain. It crosses Malo accompanied on the east, as it has been all the way from Schio, by steeply upturned fragments of the lower Mediterranean Schio-beds, then strikes through the neighbourhood of Vicenza and forms the eastern boundary between the Colli Berici and Euganaean hills on the one hand and the plain on the other. Its direction lies between north-west and north-north-west; its length from its origin to its termination near Battaglia amounts to about seventy kilometers[1].

West of this line lies the Tertiary hill land of Vicenza, and this, together with the Colli Berici and the Euganaean hills, forms a long projecting spur, which sinks beneath the plain of the Po, along a line from Verona to Este. No causal connexion can be traced between the Eocene and Oligocene eruptions of basalt and trachyte in this neighbourhood and the great fault of Schio, which is younger, and along which, as we have said, lower Mediterranean beds are upturned. The whole of this region

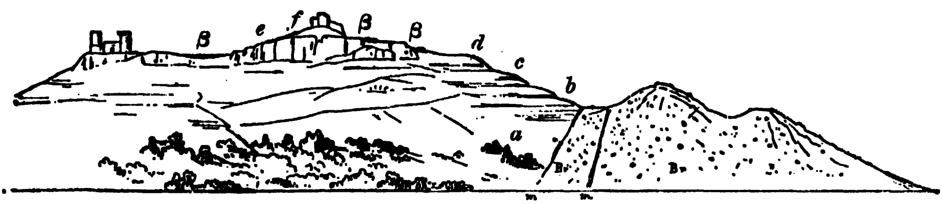



FIG. 84. *Castles of the Montagues and Capulets to the west of Vicenza.*

*Br.* basaltic brecciola; *a* Bryozoa marls; *b* great Rostellarias, Crassatellas, above *Ostrea rarilamella*; *c Clypeus Breunigi*; *d* coral limestone; *e* Lithothamnium limestone; *β*, *β*, *β* very small accumulations of basaltic tuff belonging to a horizon not definitely determined; *f* (below the castle of the Montagues) siliceous limestone with corals; *m*, *m* fissures, that on the left with fossils from the horizon of Sangonini, that on the right with fossils from the horizon of Castel' Gomberto.

has the structure of a shallow basin; in its most southerly part, between Este and Battaglia, the Cretaceous formation makes its appearance and extends over a large area, and at Fontana Fredda, a locality mentioned on p. 146, even the upper Jurassic reappears.

It is affected by subsidiary disturbances, some of which may be seen to the south-west of Vicenza; e.g. at the castles of the Montagues and Capulets, where fissures containing soft marl with well-preserved Oligocene marine shells accompany the fault along which the volcanic breccia of amygdaloid basalt abuts against the middle Tertiary beds.

[1] This great fault was recognized by Schauroth in 1855; in its northernmost part Bittner has observed an upward flexure of the western limb, while from Schio towards the south the eastern down-thrown limb is turned up: Verhandl. geol. Reichsanst., 1879, p. 77. It is precisely the same phenomenon which was mentioned on p. 131 as occurring on the fractures of the Colorado Plateau.

In the part of the southern Alps which we have hitherto discussed, the following dislocations may therefore be observed. First, long flexures, passing in places into faults which are parallel to the line of the Judicaria, are dropped on the east, and also overthrust towards the east or more exactly from west-north-west to east-south-east. These extend from the Judicarian line up to the left bank of the Adige below Peri. Next, there are similar flexures, which, lying to the south of the fractures of the Asta, run more or less parallel to them, are dropped on the southern side, and sometimes overthrust in the same direction. Some of the Judicarian flexures, chiefly in the vicinity of the Etsch valley, bend round in a sharp curve, taking the direction of the flexures of the Asta.

The amount of the throw in each flexure decreases as a rule in proportion as we leave behind us the faults of the Judicaria and of the Cima d' Asta and approach the plain.

Finally, in addition to the flexures, rectilinear faults occur, arranged roughly like a fan and with a down-throw on the east side; these maintain a north-to-south direction from the Nonsberg into the northern part of the province of Verona; from Montecchià one of these faults runs to the north-north-west, and the last branch of this group appears to be the fault of Schio, which is directed still more to the north-west.

While the significance of the flexures decreases towards the plain, that of these lines increases in the direction of the fault of Schio; this at least would seem to be suggested by the importance of the last two lines of this group.

*Dislocations to the north of the faults of the Cima d' Asta.* The mass of the Cima d' Asta together with the porphyry stands towards all the disturbances we have so far enumerated in the relation of a great horst. The horst itself is traversed by several great dislocations, which likewise give rise to step-like subsidence, but *this subsidence takes place not towards the south but towards the north.* E. v. Mojsisovics and his fellow worker R. Hoernes have established this remarkable fact, and what I shall have to say with regard to this region is borrowed almost exclusively from the admirable descriptions of the first of these authors [1].

The margin of the porphyry sheet from its south-west corner at Lavis, in the Etsch valley, runs in a fairly straight line north-east towards Truden, to the east of Neumarkt, and it appears to find its direct continuation in a line of disturbance which extends transversely across the whole porphyry region, nearly as far as the mountains of Latemar, with a strike which trends more and more to the east-north-east and a down-throw on the

[1] Edmund Mojsisovics v. Mojsvár, Die Dolomitriffe von Südtirol und Venetien, 8vo, Wien, 1879, and map; general view of the disturbances on p. 515 et seq.; for the line of Truden, p. 135; line of Tiers, pp. 131, 181; line below the Langkofel, p. 193; line of Villnöss, pp. 123, 206, 220, 255, 265, et passim.

north. This is the *line of Truden*; it is the more remarkable since it lies nearly midway between the great fault of the Val Sugana and the Judicarian fault, and is at the same time intermediate in direction.

Another important transverse fault in the porphyry is the *line of Tiers*; it begins near Virgl in the immediate neighbourhood of Bozen, runs to the east-south-east to Tiers, on the eastern border of the porphyry, and is continued as a flexure of about 800 meters throw between the Rosengarten and the Schlern. Here also there is a drop on the northern side along the whole course of the line.

A similar flexure bounds on the north and north-west the noble pyramid of the Langkofel.

The river Eisack crosses the porphyry in a trough-subsidence, which is formed by step-faults nearly in the direction of the Judicarian line, and to the north of these faults, near the mountain village of Klausen, that important dislocation begins which Mojsisovics has designated the *fault-line of Villnöss*. We will examine this line in detail.

The phyllite, which crops out towards the north from beneath the porphyry, contains to the north and north-west of Klausen a number of intercalated diorite laccolites. These masses, according to Teller, who has investigated their structure and contact-zones, are 'to be regarded as intrusive cores, which have been revealed as isolated bosses amidst the surrounding stratified rocks by the denudation of their sedimentary covering[1].' These are the characters of true laccolites. Since pebbles of the same diorite have been observed by Teller in the Permian conglomerates beneath the porphyry, these intrusions must be of great age. The two largest of these bodies end abruptly on the east-south-east along a fault with a down-throw on the north. This fault has been revealed with an unusually steep hade in the superposed galleries of the Pfundererberg at a height of more than 400 meters, but the throw of the dislocation must be much greater still[2]. This is the western extremity of the fracture of Villnöss.

This fracture crosses the Eisack, runs through the valley of Villnöss, and exhibits on its down-thrown northern side patches of porphyry in the midst of the mica-schists and finally also a spur of Trias. In the middle of the Villnöss, Mojsisovics estimates the throw of the dislocation as at least 800 meters. The fault now enters the Trias mountains, and here, according to Hoernes, the throw has much diminished; towards Campil it rapidly increases again. To the south of it, in the mountains of Gar-

[1] F. Teller and C. v. John, Geologisch-petrographische Beiträge zur Kenntniss der dioritischen Gesteine von Klausen in Südtirol; Jahrb. geol. Reichsanst., 1882, XXXII, pp. 589–684, 2 plates, in particular pp. 636 and 672.

[2] Teller believes that this fracture represents at the same time an eruptive canal of the laccolites; its steep hade is shown in F. Posepny, Die Erzlagerstätten am Pfundererberg, Archiv f. prakt. Geol., 1880, I, pl. x, figs. 2, 3.

denazza, a great trough-fault occurs, with a throw of at least 1,000 meters, which brings patches of Cretaceous into contact with the Rhaetic walls; the fault of Villnöss itself is accompanied by parallel faults of greater or less importance, and from the valley of Wengen eastwards it is *no longer the northern* but *the southern side which is thrown down*. The fault thus proceeds obliquely through the mountains of Fanes and reaches the valley of Ampezzo near Peutelstein; through this district it is accompanied by troughs, as for example that below the Croda di Antruilles, in which bands of Cretaceous wedged in between Rhaetic masses have been preserved from denudation.

The fault now traverses the mass of Monte Cristallo from which the high and long ridge of Monte Pomagagnon had been faulted down towards the south and south-west. Again a trough is formed; the faults terminate before they reach the valley of the Mesurina, but almost immediately a new and very considerable one begins a little further to the south in Val Buona, which is evidently a continuation of the fault of Villnöss bent out of its original direction. This follows the northern margin of Monte Marmarole towards Auronzo and thence to the Comelico.

As in the fault of Villnöss, to the east of the valley of Wengen, it is no longer the northern but the southern side which is down-thrown, so again the southern side is down-thrown in the case of the more or less parallel faults and flexures which accompany this fault towards the south as far as the fractures of the Asta; we may cite as examples the fracture which intersects Monte Antelao and the line of Fauzarego.

But let us return to the line of Villnöss. Its most eastern part is well known from the works of Harada. From the Val Buona onwards it is directed more and more to the east-north-east, and is thus nearly parallel to the eastern part of the line of Val Sugana. Starting from the Piave the two lines now run beside each other at a distance of 8–10 kilometers, and are united by transverse fissures, which stand almost at right angles to them. Beyond the Comelico inferiore, at the foot of the Terza piccola, the fault of Villnöss suddenly turns almost at a right angle to the north-north-west, and surrounds the phyllite region of Monte Zovo; it then reappears for a certain distance near Zappada as the fracture of an arch. Harada's works show that, all along the most northerly part of the line of Val Sugana, the northern instead of the southern side is down-thrown; but the very considerable subsidence along the transverse fault of the Val Frisone may have had some share in producing this reversal.

To the south of the line of Val Sugana the beds sink southwards in a great flexure to the Tagliamento[1].

[1] Toyokitsi Harada, Ein Beitrag zur Geologie des Comelico und der westlichen Carnia; Jahrb. geol. Reichsanst., 1883, XXXIII, pp. 151–188, 2 plates, in particular pp. 153 and 186. The overfolding of the flexure of Tagliamento in front of the fault which bounds

*The faults of the Drau and Gail.* The structures which now present themselves are of a fundamentally different character.

The part of the southern Alps with which we have so far been occupied is bounded on the west by the Judicarian line, on the north, first by the granite mass which extends from the region south of Meran almost to Brunneck, and next by the region of phyllites which make their appearance from below the outcrops of the Permian and Trias beds. These beds extend from the middle Enneberg in a gentle curve to the east towards the sources of the Drau, near Inichen, and thence, continuing the curve, they assume a south-easterly direction, so that the phyllites descend fairly low down into the valley of the Piave, where they are bounded by the eastern extremity of the fault of the Villnöss.

This vast region, which extends from Lake Idro to Meran, to the sources of the Drau and to the upper Piave, and includes a large part of the limestone mountains more to the east, resembles a great dish. The country descends to the Venetian plain by numerous fractures and flexures, but in the western half a great horst rises, the mass of the Cima d' Asta, which has not only survived the general subsidence and thus produced the mighty fractures on its south side, but has also led to a subsidence with an opposite, i.e. northerly down-throw, which extends from this southern side far towards the north, indeed nearly as far as the boundary of the granite in that direction [1].

The outcrop of Permian and Trias, which rises above the phyllite and forms the edge of the 'dish' to the north and north-east, is regarded by all observers as a denudation scarp. Loretz has published a series of excellent sections of this feature [2]. It is certainly not a fault, although the face of the Trias sometimes rises from the phyllite so steeply as to suggest that it might possibly be a denuded flexure.

Let us now cross the edge of the 'dish.'

We have only to refer to a map of the Alps to see that the Drau makes two knee-like bends in its upper course. It turns first to the north-east towards Lienz, then to the south-east towards Oberdrauburg, this is the first bend; then comes the second, in the angle of which Sachsenburg lies, and the straight reach which begins close to the east of Sachsenburg and extends nearly to the confluence of the Drau with the Gail, near Villach, is parallel to the stretch between Lienz and Oberdrauburg. The valley of the Gail,

the fragment Ugoi-Lavinamondo (p. 178) strongly recalls the relation of the flexure of St. Orso to the fault of Schio.

[1] All the essential features of this interpretation, and particularly the importance attached to the 'striking localization of the northern faults,' are to be found in the first general description of this network of faults by Mojsisovics; Dolomitriffe, p. 515 et seq.

[2] H. Loretz, Das Tirol-Venetianische Grenzgebiet der Gegend von Ampezzo; Zeitschr. deutsch. geol. Ges., 1874, XXVI, pl. viii, fig. 1–5; pl. ix, fig. 6.

on the other hand, is straight and directed to the east-south-east, and this direction it maintains from its source not far south of the Drau to the south foot of Mount Dobratsch near Villach, that is, not far from its confluence, for a distance of more than 100 kilometers. These lines of valley-bottom thus mark out in the midst of the Alps a région which on its south side extends to the east-south-east in a straight line along the Gail from Sillian to the Dobratsch, and on the north side projects in two wedge-shaped pieces; the apex of one of these lies near Lienz, that of the other near Sachsenburg. It was of this region that Leopold von Buch published a geological sketch-map in 1824, which may still be usefully consulted in studying the following description [1].

A traveller coming from the Brenner or the Etschthal, and proceeding by train through the narrow valley of the Drau between Sillian and Lienz, will see on his right hand lofty scarps of limestone, and in some places the violently contorted red beds of the Lias, while on his left the slopes are formed of gneiss and ancient schists. The line Sillian-Lienz is thus a line of dislocation, as is also the outer side of the wedge, Lienz-Oberdrauburg, and the fault is continued in a straight line through the valley of the Gitsch to the south-east, almost as far as the river Gail, near Hermagor, where, inclining a little more to the east, it joins the group of faults along which the marine Carboniferous is visible to the south of Bleiberg. This is the *fault of the Gitsch* [2].

The triangular space bounded by the line of the Drau from Sillian to Lienz, by the fault of the Gitsch, and by the valley of the Gail, has been often described, in particular by Emmrich and Stur [3]. The structure of this fragment, apart from less important disturbances, is as follows.

The beds strike obliquely across the triangle from east to west. The slopes of the Gail consist entirely of phyllites; upon these succeed some remains of porphyry sheets, then red Gröden sandstone, forming a conspicuous bed visible from a great distance, and finally the Trias, rising in beds of great thickness to a considerable height. Towards the north the overlying platy limestones of the Trias (Plattenkalke) plunge steeply downwards, forming mighty walls, against the foot of which lie Rhaetic beds

[1] L. v. Buch, Ueber die karnischen Alpen: ein Schreiben an d. Geheimrath v. Leonhard, Mineral. Taschenb. für 1824, pp. 396–437, pl. iv; also L. v. Buch's Gesamm. Schriften, published by Ewald, Roth und Dames, III, 1877, in particular p. 177 et seq. pl. v.

[2] This has been described by E. v. Mojsisovics, Verhandl. geol. Reichsanst., 1872, pp. 351–353; the fractures near Bleiberg have been fully discussed by me in Aequiv. des Rothliegenden, I, Sitzungsber. k. Akad. Wiss. Wien, 1868, LVII, p. 252 et seq., pl. i.

[3] H. Emmrich, Notiz über den Alpenkalk der Lienzer Gegend, Jahrb. geol. Reichsanst., 1855, VI, pp. 444–453; D. Stur, Geol. Verhältnisse der Thäler der Drau, Isel, Möll und Gail, op. cit., 1856, VII, pp. 414–424, and geological sections. Mojsisovics has recognized some faults in the south which I do not consider sufficiently characteristic of the structure of the district to deserve detailed mention here: Verhandl. geol. Reichsanst., 1873, pp. 235–237.

rich in fossils, and the thin-layered, much-crushed beds of the Lias. This series, of great thickness and inclined to the north, extends nearly to the apex of the triangle, but before reaching it the Rhaetic stage suddenly crops out again on the other side of the Lias; the limestone reef of the Rauchkofel, near Lienz, represents the Trias; around the little lake of Tristach the red Gröden sandstone reappears, and beneath it the phyllite, which occupies a small area in the Heimwälder near Lienz, and forms the northernmost part of the wedge-shaped fragment.

We might therefore describe this region as the segment of an east-to-west synclinal, but the northern limb is so slightly developed as compared with the southern, and confined so exclusively to the corner of the triangle, that the whole district resembles more nearly a triangular monoclinal fragment inclined to the north, and with its summit flexed or thrust upwards.

The line of the Drau, which forms the west side of the triangle from Lienz to Sillian, appears, from the observations which have so far been made, to be a very important line of dislocation. Although, as we have said, phyllite and gneiss may be seen on the left bank of the Drau, yet Emmrich has also observed Rhaetic beds on this side at a single locality—the Lienzer Klause [1].

It has only quite recently been shown by Teller that this region is traversed by two folds of Mesozoic limestone, which resemble in many respects the Trias fold of the Penserjoch described on p. 246. The first band is not more than two and a half kilometers long; it occurs in the middle of the schist and gneiss region, to the west of Inner-Villgraten, is very steeply inclined to the south, and consists of Diplopora limestone; it appears to be accompanied by Verrucano. The second band is much more important and begins near Winbach, not far from Sillian; Trias and Lias containing Belemnites may be clearly distinguished in it; it is only separated from the Drau by a cone of débris. Teller has traced it from Winbach along the valley of the Drau towards the west, and for thirty-three kilometers up to the dolomite reef of the town of Brunneck (Fig. 29, p. 245). This band is a fold in the phyllite overturned towards the south. The Lias at its eastern extremity consists of the red beds of Adneth and spotted marls (Fleckenmergel), as in the mountains of Lienz. Teller even considers it probable that this long band is only the deflected prolongation of the Trias band of the Rauchkofel, that is to say, a part of the wedge-shaped area of Lienz [2].

It is certain that immediately to the north of the outcrop which we

[1] This corresponds with the occurrence of Alpine limestone near Bannberg mentioned by Stur.

[2] F. Teller, Neue Vorkommnisse diploporenführender Dolomite, Verhandl. geol. Reichsanst., 1883, pp. 193-200.

have described as the edge of the 'dish,' a region begins within the phyllite region in which the structure and formation of the country are different, and this extends even to near Brunneck, on the south slope of the Pusterthal. In place of the broad dish-like subsidence, narrow folds occur, pinched into the schist, and the character of the deposits themselves recalls the northern Alps, as Emmrich long ago perceived.

We now turn to the eastern side of the triangular region of Lienz.

The structure of the wedge, at the northern apex of which Sachsenburg lies, differs from that of the Lienz wedge. Whereas in the latter the phyllite was chiefly visible in the south, only a very small fragment appearing in the north, and the Mesozoic deposits generally were inclined to the north, in the wedge of Sachsenburg, on the other hand, the northern part consists for a great distance of phyllite with an intercalated band of marble, while in the south, or along the Gail, the older formations only appear over comparatively small areas along great fractures [1].

It is not necessary to enter further into the structure of this region. We have seen how the winding course of the Drau is determined by faults; how the wedge-shaped area of Lienz thrown down to the north projects into the older formations, as though it were resisting a force acting from the north, and, further, how the great fold of Brunneck, which so closely resembles the limestone zone of Pens, is overturned

[1] In few places does the significance of the great lines of fracture in the structure of the Alps appear so forcibly as in the western part of the Sachsenburg mass, as for instance on a walk from Lind in the valley of the Drau, going south to St. Lorenzen, on the fault of the Gitsch. The ascent begins in the Fellbach above Lind. We walk over micaceous phyllites dipping south, which alternate with green layers towards the summit. These are followed by Gröden sandstone dipping south, and in a beautiful section the lower Trias, standing almost upright, with layers containing *Spirifer fragilis*, *Retzia trigonella*, &c. At the summit of the ridge lies bluish-grey stratified marble, dipping 50-60° south, and a little to the west. We descend towards the Weissensee over numerous outcrops, since the Trias limestone is more steeply inclined towards the south than the declivity. The lake lies almost in the strike, we cross it at its narrowest part; on the other side we ascend first over white dolomite, then over black shales with remains of fishes and crustacea, probably the fish shales of Raibl, here associated with beds of hornstone; it dips only 30-40° south, and a little to the west. We have now ascended the second ridge, and enjoy a glorious view of the southern peaks; the same inclination is maintained; below the Lorenzen hut brown shale occurs with numerous shells of Cardita. The dip is 45° south. The shale is followed by dolomite exposed in great cliffs. In descending we meet with stratified limestone; this is the 'Plattenkalk.' The inclination of the beds is steeper, and finally becomes vertical, when they describe some S-shaped curves; a short slope follows towards St. Lorenzen; over this short distance the Plattenkalk becomes inverted, dips 30° to the north, and assumes a fan-like arrangement. We have now reached the bottom of the valley of the Gitsch. The green slope on the other side is formed of phyllite. Every trace of the mighty series dipping to the south, which we have followed from the Köhlerhaus above Fellbach, has completely disappeared. The distance as the crow flies amounts to 9 kilometers, the thickness of the beds to at least 3-4 kilometers. The whole series is thrown down along the fault of the Gitsch.

towards the south. The structure of the Sachsenburg wedge differs from that of the great 'dish'; the lithological and palaeontological characters of many of its members are also different. The limestone zone is one and the same throughout; we have traced it from Villach, many miles towards the east, across Carinthia into the south of Styria, up to the south foot of the Bacher mountains south of the Drau, and we have now seen that it continues as far as the town of Brunneck.

In the angle formed by the scarp of the great 'dish' with the region of Lienz the *Carnic Alps* begin, a range which is characterized by the


FIG. 35. *Northern border of the Palaeozoic zone to the south of Hermagor.* Fracture in the upper part of the trough of the Duka, Watschiger Alpe, south side of the Gartnerkofel.

*a*, *b* Boundary between the nipped-in Carboniferous beds and the white limestone of the middle Trias.

presence of fossiliferous deposits of upper Silurian and Carboniferous age. In particular the Graptolite slates must be mentioned, which were first observed by Stache in Carinthia, and then by Taramelli in the adjacent regions of Upper Italy[1].

The structure of this region is very complex, and I will only give my opinion on the eastern part, with which I have become acquainted by repeated visits of some duration. South of Hermagor the Palaeozoic series is confined to the middle of the range, and it is easy to understand that

[1] The latest description is by G. Stache, Aus dem Westabschnitt der karnischen Hauptkette. Die Silurformation des Wolayergebirges und des Paralba-Silvellarückens; Verhandl. geol. Reichsanst., 1883, pp. 210-216.

the mighty masses of light-coloured Trias limestone in the north and south should have been considered as normally superposed, or even regarded as representatives of the Permian period. They owe their position, however, in the north as in the south, to subsidence along longitudinal faults, and the mass of the Gartnerkofel, so well known to botanists as the home of the wonderful *Wulfenia Carinthiaca* and so rich in Trias fossils, is separated from the Carboniferous by a down-throw along a sharply marked fault. Similar phenomena occur to the south near Malborghetto and Pontafel. The down-throw of these faults is extremely great, but it is impossible to give a numerical estimate.

*The faults of the Karst.* Near Caparetto, on the upper Isonzo, is to

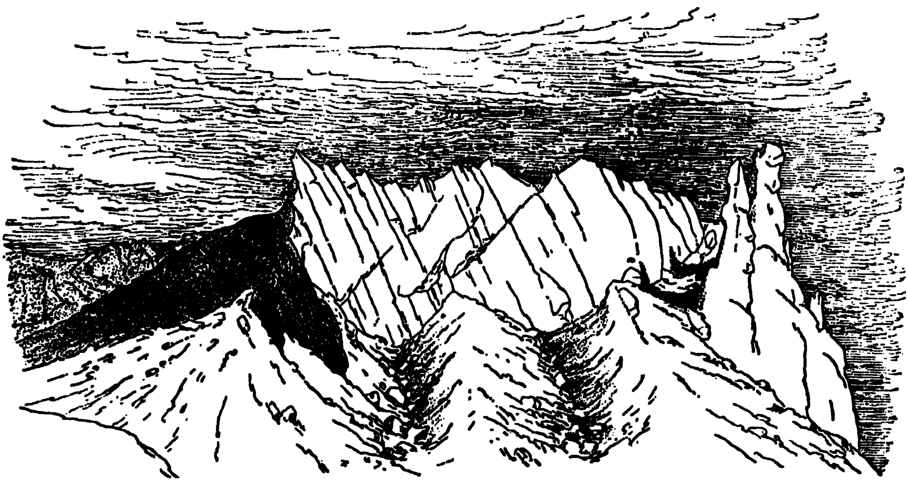


FIG. 36. *South side of the Palaeozoic zone south of Hermagor.*
Faulted down limestone of the middle Trias on contorted Carboniferous beds; crest of the Loch, Zirkelspitzen, to the north of Pontafel.

be seen the first of several long lines of dislocation which extend from this locality at least as far as Antivari (i. e. through four degrees of latitude), and proceed probably much further still towards the south; striking constantly to the south-east, they determine the structure of the country along the whole of the eastern coast of the Adriatic Sea.

In no other region in Europe are dislocations known of such extraordinary length and regularity. For its exploration, so far as the Karst district, western Croatia, and the whole of Dalmatia are concerned, we are indebted to the noble emulation of Austrian geologists. Stur has described the north-western part along the Isonzo[1]; Stache, Istria

[1] D. Stur, Das Isonzothal von Flitsch abwärts bis Görz, &c.; Jahrb. geol. Reichsanst., 1858, IX, pp. 324-367, and pl. On p. 366 there is an excellent description of the passive overthrusting of the great tabular limestone mountains over the Eocene marls and sandstones of the down-thrown side. For the upper Isonzo cf. also F. v. Hauer, Sitzungsber. k. Akad. Wiss. Wien, 1857, XXV, p. 328 et seq.

and the adjacent districts[1]; Hauer, the whole of Dalmatia[2]. But it was only when western Dalmatia and Herzegovina had been investigated that Mojsisovics was able to point out their connexion with the sunken area of the southern Alps[3], and that Bittner could show that the same lines of dislocation continue unaltered right into Herzegovina[4]. Tietze, finally, has traced them still further to the south in Montenegro[5]. They are, without exception, flexures or faults, of which the southern flank, or that nearer the sea, is let down and sometimes over-ridden by the north-eastern flank. The structure of the flexures of the South Tyrol is thus repeated on a grander scale; there, however, subsidence and over-folding take place, first to the south-east and afterwards to the south, but here to the south-west. Thus the subsidence of the Dinaric chain is directed towards the depths of the Adriatic Sea.

The manner in which these lines of dislocation penetrate into the Alps is worthy of some consideration.

According to Stur, a great fracture running nearly east and west intersects, east of Caporetto, the mountains of Dachsteinkalk, which form the mighty Krn and the heights to the south of the Wocheinthal, and the Dachsteinkalk is thrust towards the south over the down-sunken Cretaceous limestones. This fault appears to be but the prolongation of that long line of dislocation which, as Taramelli has shown, runs from Barcis through Gemona to Starasella near Caporetto.

To the south of this main fracture the first of the lines which run to the south-east makes its appearance. It does not seem to accord with the direction of the preceding line; but corresponds with the course of the Isonzo near Tolmein, is continued in the valley of the Idria, towards Tribussa, and near the mountain town of Idria (where it is accompanied by many subsidiary faults) it brings the overthrown and completely inverted deposits of the Carboniferous and Trias for a long distance into immediate contact with the down-sunken Cretaceous limestone[6]; and then proceeds past Zirknitz towards Laas.

A second line appears to the south-west of Canale, runs north of Görz

[1] G. Stache, Die Eocängebiete in Innerkrain und Istrien, Jahrb. k. geol. Reichsanst., 1859, X, pp. 272–332, pl. viii; 1864, XIV, pp. 11–116, pl. i, and 1867, XVII, pp. 243–290, pl. vi.

[2] F. v. Hauer, Erläuterungen zur geol. Uebersichtskarte der österr. Monarchie, op. cit., 1868, XVIII, pp. 431–454, et passim; G. Stache, Geol. Uebersichtskarte der Küstenländer von Oesterreich-Ungarn, 1878, fol.

[3] E. v. Mojsisovics, E. Tietze und A. Bittner, Grundlinien der Geologie von Bosnien-Herzegowina, Jahrb. geol. Reichsanst., 1880, XXX, pp. 17, 21; cf. Entstehung der Alpen, p. 92.

[4] Bittner, tom. cit., pp. 265, 269.

[5] E. Tietze, Geologische Uebersicht von Montenegro, op. cit., 1883, XXXIV, p. 92.

[6] M. V. Lipold, Erläuterungen zur geol. Karte der Umgebung von Idria, op. cit., 1874, XXIV, pp. 425–456, pl. ix, x; also Stur, Verhandl. geol. Reichsanst., 1872, pp. 234–240.

at the foot of the mountain masses of the forests of Tarnowa and Birnbaum, which are thrust over the down-thrown areas; it has been followed by Stache along the fault of Buccari, north of Fiume, as far as the sea-coast near Novi, and even into the island of Veglia, where it splits up into multiple fractures.

A third line begins close to the sea near Duino, to the north-west of Trieste; it runs obliquely across the Istrian peninsula and resolves itself here into a number of step-faults. These Istrian dislocations are prolonged further in the west of Veglia, on the island of Cherso, on Lussin, and Uniel.

Thus run these great lines of disturbance, sometimes in smaller numbers, sometimes multiplied by splitting up; one of them forms a great part of the coast of Dalmatia. To trace them, however, in detail to the south-east would be to exceed the limits of my present task.

*Enlargement of the Adriatic Sea.* The marine sediments of the middle Tertiary in the north do not extend very far towards Bosnia, while the younger deposits which occur here and there in the west of that country, and throughout the peri-Adriatic region, from Istria to Montenegro, have been laid down in fresh water. Those parts of the coast lying within the region of the lines of dislocation, as well as the numerous islands, are quite free from the more recent marine deposits, which are frequently met with over wide areas on many parts of the Mediterranean coast. The little island of Pelagosa, lying in the middle of the Adriatic Sea just at the spot where the western and eastern archipelagos approach one another most closely, is the most northerly point at which these deposits are known, and Stache regards the chain of islands—Lagosta-Pelagosa-Tremiti—as marking the south coast of the once existent Adriatic continent [1].

There are indeed a number of outcrops along the east coast of Italy, which may be regarded as fragments of the in-sunken Dalmatian plateau. The first of these is Monte Conero, near Ancona; the second, which is much more important, consists of the broad and complicated promontory of Monte Gargano. This rises in some places to a height of over 1,000 meters; it is cut off abruptly on the side facing the Apennines, from which it is separated by a depression filled with recent marine formations. Its steeply inclined strata consist, according to Bucca, of Tithonian, Cretaceous, and Eocene limestone and marl [2]. Finally, in

[1] G. Stache, Geologische Notizen über die Insel Pelagosa, Verhandl. geol. Reichsanst., 1876, pp. 123-127; cf. also Stur, op. cit., 1874, p. 391; for the Adria cf. also Mojsisovics, Dolomitriffe, p. 531; Marchesetti, Descrizione dell' isola di Pelagosa, Boll. Soc. Sci. Nat. Trieste, 1876, II, pp. 283-306; R. F. Burton, A Visit to Lissa and Pelagosa, Journ. Geogr. Soc., 1879, XLIX, p. 184 et seq.

[2] L. Bucca, Appunti geologici sui monti del Gargano; Boll. Com. Geol. d' Italia, 1881, XII, pp. 556 and 563.

this category we must also include the great outcrops of Cretaceous limestone which occur in the Murgie of Bari and beneath the younger deposits of Apulia to beyond Otranto[1]. The contrast between all these districts and the Apennines is so great that de Giorgi proposed to regard them as an independent orographic system, 'the Apulo-Garganian group[2].'

In confirmation of the theory that communication by land may have existed across the existing Adriatic, Neumayr points out that according to Kobelt the molluscan fauna at present met with on Monte Gargano presents characters which are not Italian but Dalmatian[3].

Numerous other indications of this communication may also be observed. On the east coast of the most southerly part of the peninsula of Istria very recent masses of sand are met with above the well-known *terra rossa*, and these are continued on to the little western islands of Unie, both the Canidole and Sansego; Stache and Marchesetti have lately examined these islands, and Marchesetti has found beneath the sand of Sansego a hard layer containing the shells of living species of land-shells. The two observers regarded these deposits as the sediments of a large river[4].

In many of the islands the remains of great terrestrial animals are found in breccias; thus Neumayr and Woldrich point to the occurrence of the horse, bison, stag, and rhinoceros on Lesina as a proof of the previous communication of this island with the mainland[5]. The most remarkable case of this kind appears to be furnished by the little reef of Silo not far from the south peak of the Canidole piccola. According to Marchesetti this rock, the surface of which only measures a few square meters, lies so low that it is completely covered by the sea at every spring tide. Notwithstanding this the remains of large ruminants are found in its breccias[6]. It is a well-known fact that on several of the Dalmatian islands the jackal (*Canis aureus*) is still to be found living at the present day.

There is however every reason to suppose that the movements which have enlarged the Adriatic in comparatively recent times are not yet concluded. The region of the peri-Adriatic faults is at present subject to

[1] C. de Giorgi, Note stratigrafiche e geologiche da Fasano ad Otranto; Boll. Com. Geol. d'Italia, 1881, XII, pp. 187–203, pl. iv.

[2] The same, op. cit., 1879, X, p. 622.

[3] M. Neumayr, Ueber den geologischen Bau der Insel Kos, Denkschr. Akad. Wien, 1879, XL, p. 263, note; Kobelt, Jahrb. deutsch. malakoz. Ges., 1879, p. 144.

[4] Stache, Verhandl. geol. Reichsanst., 1872, p. 221; C. Marchesetti, Cenni geol. sull' isola di Sansego, Boll. Soc. Adriat. Trieste, 1882, VII, pp. 289–304.

[5] M. Neumayr, Verhandl. geol. Reichsanst., 1882, p. 161; J. Woldrich, Beiträge zur Fauna der Breccien, &c., Jahrb. geol. Reichsanst., 1882, XXXII, p. 454 et seq.

[6] Marchesetti, loc. cit., p. 300.

frequent seismic movements of the most varied description. According to the observations of Bittner and Hoernes[1] it may be inferred that the great earthquake of Belluno which occurred on June 29, 1873, took place along two parallel surfaces of horizontal dislocation or true flaws directed to the north-north-east; starting from the south side of the Alps it crossed this chain and extended right into the mass of Bohemia; it thus presented a close resemblance to those earthquakes which occur on the north side of the Alps. I am not able to offer any explanation of this kind of concussion, which proceeded from within the sunken area outwards. Other flaws accompanied by horizontal displacement are also present, near Raibl, for example, and in the valley of Weissenfels, and it is not improbable that the great earthquake of Villach in 1348 was also a transverse earthquake.

But it is a well-known fact that Zengg, Zara, Ragusa, and other parts of the Dalmatian coast, which have been formed by lines of dislocation, have repeatedly been the seat of most violent concussions, and Hoernes justly points out that in the years 1869 and 1870 the line of the Karst passing through Görz-Klana-Fiume-Ottocac, i.e. the second of the lines of dislocation mentioned on p. 267, served as the path of wandering seismic centres, and resembled in all essential respects the peripheral Calabrian line of 1783. Tietze has made similar observations on the line of dislocation near the coast of Montenegro close to Antivari[2].

Just as we speak of a submerged Tyrrhenis and seek, by means of zoo-geographical and phyto-geographical studies, to discover the relationship and connexion between such of its remaining fragments as rise above the level of the sea, so we may likewise speak of an Adriatis submerged in later times, and endeavour to determine its outline, although the recent deposits on the outer slopes of the Apennines and on the margin of the plain of Lombardy render it probable that during its existence there was a free communication of the sea between Gargano and the Apennines. The events which occur on the seismic line of Calabria reveal the continuation of those processes by which the mainland sinks piece by piece towards the interior, and on the line of dislocation which separates

[1] Bittner, Beiträge zur Kenntniss des Erdbebens von Belluno vom 29. Juni 1873, Sitzungsber. Akad. Wiss. Wien, 1874, LXIX, 2 parts, p. 541; R. Hoernes, Erdbebenstudien, Jahrb. geol. Reichsanst., 1878, XXVIII, pp. 387-448, pl. xi. For the concussions in the Southern Alps in connexion with the lines of dislocation, see in particular H. Hoefer, Die Erdbeben Kärntens und deren Stosslinien, Denkschr. Akad. Wiss. Wien., 1880, XLII, 90 pp., 3 pl. (p. 87 in-sinking of the Adria), and R. Canaval, Das Erdbeben von Gmünd am 5. November 1881, Sitzungsber. Akad. Wiss. Wien, 1882, LXXXVI, pp. 353–409, 2 pl.; Tietze, Geol. Uebersicht von Montenegro, pp. 65 and 93.

[2] Hoernes, Erdbebenstudien, p. 433, and in other places. Chiefly based on the treatise by G. Stur, Das Erdbeben von Klana im Jahre 1870; Jahrb. geol. Reichsanst., 1871, XXI, pp. 231-264, pl. ix, x.

Istria from the continent we see similar occurrence stake place before our eyes.

*Summary.* Among the results of these comparative studies none appears to me so strange as the obvious arrangement of the main ranges of the Alpine system in a more or less spiral manner, such as is represented in Fig. 26, p. 232, and on Plate iii.

At the risk of repeating much that I have already said I will now attempt to give a general survey of the arrangement of the chains and of the sunken areas.

To north and west of the Jura and of the principal chain of the Alps and the Carpathians lies a land of multiform structure. Proceeding from the west we meet first the western margin of the great horst, which is known as the Central Plateau of France; then we come to its continuation in the little gneiss mass of Dôle close to the outer edge of the Jura; at a somewhat greater distance we reach the southern margin of the Vosges, and then, close to the edge of the Jura, the southern end of the Schwarzwald limited by the border of the table-Jura. We next encounter the great Swabian Franconian subsidence, which extends from the Schwarzwald and the Odenwald to the Thüringerwald and Frankenwald, to the western margin of the Fichtelgebirge and the Bavarian Forest. One step of this great in-fall extends as far as the main fracture along the Danube. Its borders are detached from the projecting horsts along faults; the sinking, although interrupted by occasional trough-subsidences, increases towards the Danube, where isolated caldrons occur, accompanied by slight extrusions of eruptive rocks. Unmistakable examples of horizontal movement may be recognized; the eastern border of the in-sunken area is inverted in places, and in the caldron of the Ries a case of horizontal thrusting occurs.

From Regensburg towards Linz the border is sometimes overturned to the south, and the Cretaceous is involved in the folding.

On the other side of the Bohemian horst the foreland presents a different structure. The Sudetes meet the horst along a great fault, and in Lower Austria and Moravia probably lie as a whole beneath the plain. Near Weisskirchen they come into contact with the border of the Carpathians, and then dip, zone after zone, beneath them (Fig. 24, p. 186). It is possible, but has not been proved, that the numerous and mighty faults in the Coal-measures of Ostrau are connected with this subsidence.

Finally we reach further in the east the Russian Platform (Fig. 25, p. 187).

This is the foreland; now follow the folded chains.

In front of the principal chain stands the bow-like rampart of the Jura; it is crushed against the Dôle, and at its eastern end is driven

over the forelying table-Jura in repeated imbrications. Behind the Jura lies the plain of Molasse and then the Alps.

It seems to me of essential importance, if we are to understand the Alps, to bear in mind the unity of their outer border; a unity so clearly expressed from the extreme west in the south of France to the extreme east in Wallachia. In this statement we include the Carpathians, for they are the immediate prolongation of the outer parts of the main chain of the Alps. This whole border, confined between the horsts, extending unimpeded over the sunken foreland, and finally advancing towards the north in a broad arc, appears, according to all that is known of its structure, to be the *anterior margin of a superficial flake of the earth's crust over-riding a subsided foreland.*

Crossing this border we meet towards the interior of the mountains progressively older rocks, in more or less regular order, forming chains, bands, and flakes, which are folded, overthrust, or thrown down towards the front along longitudinal fractures, until far to the south we again reach a collapsed area. Multiform in structure is the foreland of the Alps, uniform their outer border, and multiform again the inner border.

Collapse or in-sinking of the inner border takes place in various ways. In the Carpathians it occurs along faults accompanied by volcanic eruptions; sometimes these penetrate deep into the mountains, as, for example, from Tokaj towards Eperies, and only the Flysch zone then remains visible; sometimes, again, the interior part of the mountains remains visible over a great breadth, as, for example, immediately to the west of the above-mentioned places. The in-sunken basin of Vienna, that on the eastern border of the Alps, near Landsee, and that more to the south between the spur of Güns and the Bacher mountains, have already been described in detail.

To the south of the Bacher that independent unilateral branch of the Alps begins, which under the name of the Mittelgebirge of Hungary runs towards the north-east to the inner side of the Carpathians; its down-sunken interior zones lie beneath the Plattensee, but remnants appear near Stulhweissenburg.

Those isolated mountains which, commencing west of Agram, rise above the plain along the Save in the south, and on the north to beyond Fünfkirchen, I regard, with Mojsisovics, as parts of a great mass alien to the Alps both in structure and composition. Against this mass is thrust the Flysch zone and intruded serpentine of the Dinaric branch, which has been prevented by the opposing mass from developing in the same typical manner as the other branches of the Alpine system. Commencing already near the depression of Laibach, there stretch down to Montenegro, according to recent investigations, elongated masses of schist, chiefly of Carboniferous

age, which much more resemble the flattened arches of the Tuscan *Catena metallifera* than the gneiss cores of the Alps. They form the oldest series of these mountains; to the west of them, and running parallel to them, begin the long fractures and flexures along which all the country on the west is down-thrown in the direction of the Adriatic sea. The Karst, together with the peninsula of Istria, is only a fragment of the same mountain system; it is traversed by the same lines of dislocation; the direction of which is clearly expressed in the zigzag course of the Isonzo.

We have now again reached the main chain of the Alps. On the Isonzo, at the points where these lines have entered the Alps, new fractures appear, which extend for a great distance as far as Meran and Lake Idro. All these great lines, from Montenegro to Lake Idro, bound the Adriatic sea on the east, north, and north-west, and may be appropriately termed the peri-Adriatic fractures.

These lines mark steps of subsidence, and at the bottom of the sunken area lies the Adriatic sea. The position of this sea is thus already determined by the structure of the southern Alps. Out of the region of subsidence, however, rises as a horst the granite mass of the Cima d' Asta in South Tyrol, and the country to the north of it subsides by steps in the opposite direction. The peri-Adriatic lines are marked over the whole area, not only by subsidence, but also by the overriding of the higher upon the depressed masses, and since the latter, with the exception of the district to the north of the Cima d' Asta, always lie next the sea, so the overthrust constantly takes place from the mountains seawards, i.e. from the higher towards the lower parts of the sunken area. In the inset mountains of the Etsch, and on Lake Garda, the thrusting is therefore directed towards the south-east, south of the Cima d' Asta to the south-south-east or to the south, but in Istria, Croatia, and Dalmatia to the south-west.

All the various peri-Adriatic lines of dislocation are, as we have seen, formed on the same plan; both vertical and horizontal movements have occurred, and all the facts appear to confirm the view which Gilbert arrived at some years ago in the west of America, namely, that the vertical movement was more deep-seated, the horizontal more superficial (p. 107).

We might naturally attempt to apply these principles to the northern Alps, and, in conformity with the views held by Monsieur Lory in the case of the western Alps, explain all the folds of the northern Alps as overthrust faults or flexures[1]. It does not seem to me, however, that this interpretation would be consistent with the facts.

We have seen that in the southern Alps both downward and tangential

[1] C. Lory, Essai sur l'orographie des Alpes occidentales, 8vo, Grenoble, 1878; Coup d'œil sur la structure des massifs primitifs du Dauphiné, from the Bull. de la section de l'Isère du Club alpin franç., II, 1878; and elsewhere.

movements occur; under these circumstances parallel flexures may pass into parallel oblique synclinals, and eventually into imbricated structure. The structure of the western Alps, which face the Central Plateau of France, may have been largely determined by great lines of fault, and, according to later observations, the case seems to be similar in the northern Alps in the neighbourhood of the Bohemian mass. But the folds of the mass of the Finster-Aarhorn, which are repeated several times, one over the other, in the same face of rock, and thus cause the Jurassic limestone to be surrounded above and below by the Trias, do not admit of such an explanation, nor do the folds of Pilatus, the Säntis, nor any of those masses which are folded on themselves. The course of the long undulations of the Jura, the movement and the compression of the Alpine chain as a whole, and the structure of the Carpathians with their long anticlinals, revealed by the petroleum workings, show an unmistakable predominance of the tangential movement. Of late years, however, a large number of subsided areas have been recognized in the northern part of the eastern Alps, and the southern boundary of the Flysch zone in particular proves in this region more and more clearly to be an immense overthrust of enormous length.

A fundamental difference, however, exists between the northern and southern part of the eastern Alps; in the north all the tangential movements are directed towards the exterior, that is, towards the Bohemian mass, while in the south, in the whole region of the southern Alps which we have discussed, this movement is directed towards the interior, or the concave side of the curve, i.e. towards the bottom of the Adriatic depression. This is that tendency to *override the subsidence* which we have already observed (p. 143) even in mountains situated outside the Alpine region (p. 138).

This subsidence occupies an area such as would be covered by a regular expansion of the Adriatic Sea, and it may therefore truly be said that the border of the Adriatic depression encroaches on the Alps as far as Meran. At the same time a glance at Pl. III shows that a most remarkable correspondence exists between the outline of the Adriatic sea, or of the sunken area in which it lies, and of the Swabian-Franconian sunken area beyond the Alps. Between the two latter lies, however, like a stiffened beam, the folded mass of the Alps.

In the southern Alps we meet, further to the west and beginning at the great flexure of the Maniva, a second region of subsidence, that of Lombardy, in the eastern part of which, on Lake Como, a flexure occurs pushed over to the south. In the interior of the Alps the peculiar volcanic mass of Adamello marks approximately the dividing line between the two regions.

Two sunken areas thus face the Apennines: that of Lombardy and that

of the Adriatic. Remains of the sunken Adriatis rise up near Ancona, at Monte Gargano and in Apulia. If the question asked above, as to where the continuation is to be found of the border of the Alps which runs south-east from Verona to Este, had any real justification; if we are right in assuming at all the existence of such a homogeneous border, then we must reply that the continuation is to be found extending from Este in an unchanged direction towards the south-east along the west side of Monte Conero, near Ancona, and still further along the west side of Monte Gargano.

The Apennines, which appear to be much more independent than any of those branches of the Alpine system already enumerated, reveal the same process as that to which the outer border of the Alps bears witness. Disregarding the diversity of the foreland, the Apennines advance in a constant unbroken curve towards the depression of Lombardy and that of the Adriatic, and their outer border, precisely like that of the Alps, would seem to be the *anterior margin of a superficial flake of the earth's crust overriding a subsided foreland.*

We now cross the Apennines and find ourselves, on its western side, once more in the region of collapsed areas; volcanos accompany them as in the Carpathians; as at Eperies, so at Florence, the Flysch zone alone remains standing; the same fragmentation of the inner border also occurs.

The *virgation* of the mountains, or the divergent sheaf-like arrangement of the several branches of the Alps, is manifested by the general advance in constant curves of the margins of crustal flakes over the variously in-sunken and fractured foreland, and thus it happens that a region which is the 'backland' of one branch forms the foreland of the next succeeding.

The folded chain is always sharply bounded on the side towards the foreland, but in the Alps its relations to the backland can only be recognized with great difficulty. Between the Dinaric chain and that of Central Hungary an ancient core of alien nature appears to be present. In the Apennines, on the other hand, the relations to the backland are clearly displayed, as Lotti[1] has lately shown. On Elba, for instance, ancient serpentine occurs beneath the Silurian beds; it is continued into the island of Giglio, Monte Argentario, and the north-east of Corsica, and probably corresponds to the great masses of ancient serpentine which occur in the western part of the southern Alps. These are followed by beds of probably Permian age, but the Trias is absent throughout the whole of the insular region, as it is also in the greater part of the *Catena metallifera* on the peninsula; and there, as here in the *Catena metallifera* in Elba and in Corsica, the Rhaetic stage lies in transgression, even occurring on pre-

[1] B. Lotti, Osservazioni geologiche sulle isole dell' Archipelago toscano; Boll. com. geol. d' Italia, 1884, XV, pp. 56–61.

Silurian rocks. In Elba a later transgression coincides with a part of the upper Lias; above this another great gap occurs over the whole region, and the Eocene beds extend transgressively in the peninsula, as well as in Elba and Corsica, over much older rocks.

The backland is thus characterized by gaps in succession and by transgressions, and the fact that the same interruptions in the normal stratified sequence may be traced into the inner chains of the folded region, and especially into the *Catena metallifera,* testifies to their former continuity.

# CHAPTER IV

## THE MEDITERRANEAN

**Five historical phases of unequal value. Relations to America. The Atlantic Ocean. Guadalquivir, Gironde, Rhone. First Mediterranean stage. The Schlier. Second Mediterranean stage. The Sarmatian inland sea. The Pontic lakes. More recent times. Northern immigrants. The latest subsidences. Summary.**

The Silurian deposits of central and southern Europe differ as a whole and in an essential manner from the contemporary formations in the North. The existence, during a considerable part of the Jurassic period, of a 'Mediterranean' as opposed to a 'North European' province is shown by conclusive evidence. The former included the Alps and Carpathians. In still later times, the influence of a warmer climate in this Mediterranean region (always including the Alps) made itself felt, as is clearly shown in the rich coral fauna of the Turonian stage in the south of France, and in the Gosau beds of the eastern Alps. Not less remarkable is the beauty and variety of form in the old Tertiary fauna of the Vicentine pre-Alps. Towards the middle of the Tertiary period, in Oligocene times, the sea extended transgressively over a large part of Europe, so large a part in fact that this Oligocene transgression is only exceeded by that of the Cenomanian; but, during this great extension of the sea, an exceedingly rich coral fauna still flourished at Crosara and Castel Gomberto; it is also represented in certain bays of the Alps, especially in the Carniola, and even in the northern zone of the Flysch on the Waschberg near Vienna. On the other hand, the contemporaneous beds of Gaas and Lesbarritz, the sand of Fontainebleau and Weinheim, present a poverty-stricken coral fauna, and contain only a few of the richly adorned mollusca of the Vicentine foot-hills; towards the north-east, in the muddy deposits of the same period, the southern character of the fauna continues to steadily disappear.

After this great transgression a fauna appears for the first time which includes a remarkable number of species still existing in the Mediterranean, and shows as a whole such close relations to the present population of that sea, that the deposits it characterizes have for some time been known among a certain school of geologists as the 'first Mediterranean stage.' This stage will serve as a point of departure for the following observations on the history of the Mediterranean.

The Tertiary deposits have been classified according to various principles and with varying success. Long ago Lyell and Deshayes distinguished

the great groups of Eocene, Miocene, and Pliocene, basing them on the percentage of surviving species, and thus created a classification which, if artificial, was at least rich in results; but since this first step was taken our knowledge has been very considerably increased. Lyell himself recognized the necessity of adding to these groups. The most important of the new members, Beyrich's Oligocene, rests not so much on the comparative number of surviving forms, as on a feature of completely different nature, namely, on its transgressive position. On the other hand, it is on palaeontological grounds that M. Hoernes bases his proposal to recombine the middle and a large part of the upper members under a common name as the Neogene group. In this connexion we must also mention the Sarmatian series, which contains extraordinarily few, perhaps indeed, with the exception of certain Rhizopods, no extant species, and yet is undoubtedly younger than the deposits of Baden or the Leithakalk, which include a high percentage of surviving species. Finally, local researches have led to a multitude of geographical designations, which if they have materially facilitated the analysis of the subject, yet have rendered more difficult the general survey of past events; and since a large number of these local series have been raised by K. Mayer and others to the dignity of independent divisions of the Tertiary formation, the system of drawing strict boundaries has, I fear, become a dangerous instrument in the service of synthesis.

It is the organic remains, no doubt, which afford us our first and most important aid in the elucidation of the past. But the goal of investigation must still remain the recognition of those great physical changes, in comparison with which the changes in the organic world only appear as phenomena of the second order, as simple consequences.

With this point in view, let us attempt to obtain a general idea of the past history of that part of Europe now in question. For this purpose we will first examine those phases in which the marine character of the deposits attains its most marked expression. These are the phases of the normal composition of sea-water, consequently of the undisturbed communication of a land-surrounded sea with an ocean, in this case, as we shall see directly, with the Atlantic. The position of the Mediterranean shows us further that, provided conditions exist somewhat similar to those of the present day, the effect produced by the cessation of an existing communication with the sea will be the greater the nearer the place of interruption approaches to the Atlantic Ocean, i.e. to the west, and hence, that we may expect in the east a more frequent interruption of the normal marine succession and a greater variety among the consequences resulting from isolation. It would thus appear from these preliminary observations, that it would be just as absurd, in the face of such an infinite diversity of events, to speak of equality between the various phases in the

history of the Mediterranean as of equality in a series of stages in the history of mankind. But even as the destiny of a nation is influenced partly by local and partly by general processes, so in the case before us. The subsidence of the northern part of the Adriatic, discussed in the preceding section, remains a local phenomenon, while the appearance of northern mollusca in the Mediterranean is the result of a general process the causes of which lie outside this sea.

For the present, however, we are only concerned with the classification of the actual facts, and with this object we distinguish, since the close of the Oligocene period, several phases in the normal state of the Mediterranean, which will be designated the first, second, third, and fourth Mediterranean stages, to which must be added as a fifth stage its present condition, with the subordinate oscillations of the coast-line observable at the present day. In each of these stages, and especially in the first and third, several subdivisions may be distinguished. Most remarkable is the second stage, owing to its extra-marine formations, which reveal an isolation of the eastern region, and separate the preceding from the following stage. But in the geographical extension of each of these stages, it is to be observed that while each includes regions already submerged during the preceding stage, yet it loses some areas which are abandoned by the sea, and acquires others over which the sea newly encroaches. The contour of the Mediterranean is therefore different in each phase.

In order to give a first general survey of these stages, and to facilitate subsequent description, we will illustrate their general significance by the following important and classic examples of Tertiary deposits.

*The first Mediterranean stage* includes the faluns of Léognan, the lower series of marine formations in the Rhone valley with the beds of St. Paul-Trois-Châteaux, the marine Molasse of Switzerland, the marine Molasse of Bavaria, the group of the Horn beds on the slopes of the Mannhart mountains, the Schio beds of Upper Italy and the Apennines, the serpentinous sand of Turin, and the lower limestone with, or at least up to, the horizon of *Orbitoides Mantelli* of Malta, Gozzo, and elsewhere.

In the east and south of Europe this stage is followed over large areas by a thick deposit of blue marl, which presents many independent characters and is frequently accompanied by deposits of gypsum and salt. This is the *Schlier*.

To *the second Mediterranean stage* belong the faluns of Touraine, the faluns of Salles, the marls of Cabrières in the Rhone valley, the deposits of Baden, Vöslau, Grinzing, Steinabrunn and the Leithakalk near Vienna, in Hungary, Transylvania and Wallachia, the series of Tortona, the upper horizons of the island of Malta.

Overlying these deposits in the valley of the Danube comes the curious Sarmatian stage, into which only a few Mediterranean types

ascend; it is distributed over an area which extends eastwards beyond that of the second Mediterranean stage and even beyond the Caspian sea and the sea of Aral.

Theobald Fuchs rightly points out that in central Italy the blue marls of the Vaticano occupy a position above the second Mediterranean stage, which is not unlike that of the Schlier at the base of the lower part of this stage [1].

*The third and fourth Mediterranean stages* include the whole series of older and younger Pliocene, that is to say, the younger marine deposits of the Rhone valley, the beds of Asti, Siena, and Monte Mario, of Gerace and Messina, of Corinth and Rhodes. In the fourth stage signs of increasing cold make their appearance.

The *fifth Mediterranean stage* comprises the present Mediterranean, including its most recent marginal deposits, which occur on the west coast of Italy, in the west of north Africa, Cyprus, and other places.

These five stages correspond in general to the middle Miocene, the upper Miocene, the Pliocene, Quaternary, and the most recent deposits, according to the terminology of French and Italian geologists, who reserve the expression lower Miocene for the 'calcaire à astéries' of the south of France, and for the beds of Gaas, Dego, and Castel Gomberto.

*Relations with America.* A series of recent observations have established the fact that the marine deposits of the west coast of South America and of the Antilles present a very close resemblance to those of Europe. This similarity presents itself even in the oldest deposits, and according to Philippi continues in Chili up to the Tertiary period, where during this interval there flourished on the Pacific coast a Molluscan fauna which is closely related in character to that existing in the Mediterranean [2]. It is only in the most recent times that this correspondence is destroyed and the present marine fauna of the west Atlantic, which is distinct from the European, makes its appearance.

Under these circumstances no history of the Mediterranean would be complete which failed to take into account the observations made on this subject on the other side of the Atlantic Ocean.

The Antilles form, as will be shown later, a mountain chain extending as a circular arc through Cuba, Haiti, Puerto Rico, and then southwards towards Trinidad. Jamaica and the south-western part of Haiti belong to an inner chain which is associated with this. The Caribbean sea has subsided along the inner side of these chains, while the foreland, in so far as it is not submerged beneath the waters of the Gulf of Mexico, consists of

[1] Theobald Fuchs, Studien über die Gliederung der jüngeren Tertiärbildungen Ober-italiens; Sitzungsber. Akad. Wiss. Wien, 1878, LXXVII, 1. Abtheil., p. 423, 'Pliocäner Schlier.'

[2] R. A. Philippi, Ueber Versteinerungen der Tertiärformation Chile's; Zeitschr. f. d. ges. Naturwiss., 1878, LI, pp. 674–685.

horizontally stratified deposits covering an area which, starting from Matamoras, probably even from Vera Cruz, extends far around the northern border of the gulf up to Arkansas and Alabama, including the peninsula of Florida, and proceeds a long way up the coast of Carolina. Nevertheless the Gulf of Mexico sinks to a depth of 2,000 fathoms or more, and the Caribbean sea also reaches this great depth near the east coast of Yucatan and the south coast of Cuba.

In Jamaica there exists, lying above a series which may be compared to the lower divisions of our Flysch, a light-coloured, highly fossiliferous limestone, the fauna of which, as Duncan, Barrett, and Woodward have shown, corresponds in the most surprising manner to that of Gosau in the north-eastern Alps. Besides *Actaeonella laevis*, Nerinaea, and numerous Hippurites, a number of the most characteristic corals of the Gosau beds appear here, as, for instance, *Diploria crassilamellosa*, *Heliastraea exsculpta*, and *Cyathoseris Haidingeri* [1].

The occurrence of these Cretaceous corals on the other side of the Atlantic leads us to suppose that at this period some sort of connexion must have existed across the ocean, either in the form of a continuous coast-line or as a chain of islands, and this supposition is strengthened by the circumstance that the same phenomenon is repeated in the Tertiary period. This fact is so striking that it has frequently attracted the attention of observers; and Duncan, Jones, Etheridge, Guppy, Cotteau, and others have published a number of admirable treatises on the subject [2].

[1] L. Barrett, On some Cretaceous Rocks in the South-eastern Portion of Jamaica, Quart. Journ. Geol. Soc., 1860, XVI, pp. 324–326; M. Duncan and G. P. Wall, A Note on the Geology of Jamaica, op. cit., 1865, XXI, pp. 1–15.

[2] Among the most important of these works are: P. M. Duncan, On the Fossil Corals of the West Indian Islands, Quart. Journ. Geol. Soc., 1863, XIX, pp. 406–458; 1864, XX, pp. 20–44 and pp. 358–374; J. Carrick Moore, On some Tertiary Shells from Jamaica, with a Note on the Corals by P. M. Duncan, and a Note on some Nummulinae and Orbitoides by Rupert Jones, op. cit., 1863, XIX, pp. 510–515; Duncan, On the Correlation of the Miocene Beds of the West Indian Islands, and on the Synchronism of the Chert Formation of Antigua with the lowest Limestone of Malta, Geol. Mag., 1864, I, pp. 97–102; Rupert Jones, The Relationship of certain West Indian and Maltese Strata, as shown by some Orbitoides and other Foraminifera, tom. cit., pp. 102–106; R. J. Lechmere Guppy, On the Tertiary Mollusca of Jamaica, Quart. Journ. Geol. Soc., 1866, XXII, pp. 281–295; On Tertiary Brachiopoda from Jamaica; On Tertiary Echinoderms from the West Indies, tom. cit., pp. 295–301; On the Relations of the Tertiary Formations of the West Indies, with Appendices by Woodward and Jones, tom. cit., pp. 570–593; Robert Etheridge, Summary of the Palaeont. of the Caribbean Area as Append. V to Sawkins, Report on the Geology of Jamaica, 8vo, 1869, pp. 306–339; Purves in Ann. de la Soc. Malacol. de Belg., 1873, VIII, Bull., pp. xxv–xxviii (only land and fresh-water shells from a siliceous limestone); Cotteau, Descript. des Echinides tert. des Iles St. Barthélemy et Anguilla, Svensk. Vetensk. Akad. Handl., 1875, XII, No. 6, and Descript. des Echin. foss. de l'Ile de Cuba, Ann. Soc. géol. Belg., 1881–1882, IX, Mém., pp. 1–49; Duncan, On the older Tert. Formations of the West Indian Islands, Quart. Journ. Geol. Soc., 1873, XXIX, pp. 548–565; L. Guppy, On the Miocene Fossils of Haiti, op. cit., 1876, XXXII, pp. 516–532, and as an

These works do not, however, seem to me to prove conclusively the existence of a true Eocene coral fauna on the West Indian islands. The Eocene coral reefs of Europe, among which I include the coral beds of Friaul[1] made known by d' Achiardi, do not appear to have been observed on the other side of the ocean.

On the other hand, the coral growths of St. Bartholomew and their equivalents in Jamaica, Cuba, and other islands correspond, according to Duncan's researches, to those of Castel Gomberto and Crosara. They also form the 'Fernando beds' of Trinidad. It is the European species, occurring in these horizons on the other side of the Atlantic, such as, for example, *Trochosmilia subcurvata*, *Trochosmilia arguta*, *Stephanocoenia elegans*, *Astrocoenia multigranosa*, *Ulophylla macrogyra*, and *Porites ramosa*, which build up and adorn the reefs of Castel Gomberto.

The next younger division of the West Indian Tertiary beds, which should perhaps be united with the preceding, is the siliceous limestone of the island of Antigua. Duncan and Jones compared it as early as 1864 with the lower limestone of Malta. The presence of *Stylocoenia lobato-rotundata* cannot indeed be regarded as very significant since this species has a wide vertical distribution in Europe; of greater importance is the occurrence of *Astrocoenia ornata*, which is also characteristic of our Turin deposits, and the abundance of *Orbitoides Mantelli*, which is equally common in the lowest deposits of Malta.

In Europe, however, there is certainly no very great difference in age between the coral fauna of Castel Gomberto and the lower limestone of Malta. According to Theobald Fuchs this limestone lies below the horizon of Schio, while its fauna resembles that of Castel Gomberto and Schio[2]. It is therefore unnecessary to suppose that any considerable gap occurs between the coral-bearing deposits of St. Bartholomew and the siliceous limestone of Antigua[3].

The succeeding deposits of white limestone in the West Indies correspond very nearly with the upper limestone of Malta, that is, with the Leithakalk

appendix to W. M. Gabb, On the Topography and Geology of S. Domingo, Trans. Americ. Philos. Soc., Philadelphia, 1873, new ser., XV.

[1] A. d' Achiardi, Coralli eoc. del Friuli; Atti d. Soc. Toscan. di Scienze Nat., 1875, II, 100 pp. and 16 plates.

[2] T. Wright, On the fossil Echinoids of Malta, with additional notes on the Miocene Beds of the Island, &c., by A. L. Adams, Quart. Journ. Geol. Soc., 1864, XX, pp. 470–491; T. Fuchs, Das Alter der Tertiärschichten von Malta, Sitzungber. Akad. Wiss. Wien, 1874, LXX, 1. Abth., pp. 92–102; A. L. Adams, On Remains of Mastodon and other Vertebrata of the Miocene Beds of the Maltese Islands, Quart. Journ. Geol. Soc., 1879, XXXV, pp. 517–531.

[3] Professor Heilprin, of Philadelphia, to whom I am indebted for instructive letters on this subject, believes the Orbitoides beds of Florida and the coral beds of St. Bartholomew and other places belong to this stage. This view is not incompatible with the results obtained in Europe.

of the second Mediterranean stage. *Cidaris Melitensis* appears on several of the West Indian islands associated with species which are closely related to some in the upper limestone of Malta, as, for example, *Schizaster Loveni* and *Brissopsis Antillarum*.

There can then be no doubt that the coral fauna of Castel Gomberto and the Orbitoides limestone of Malta are represented in the West Indian islands, and that above these deposits still younger beds of marine limestone occur. Having established these facts we may now turn to the north.

Eugene Smith has shown, in confirmation of older statements, that the peninsula of Florida is neither so low-lying nor of such recent age as is generally supposed. A ridge, which attains in places a height of over 200 feet, runs from the north throughout the length of the great peninsula; and the larger part of it, to the south almost as far as the Everglades, to the west in several places up to the sea, consists of Vicksburg limestone with *Orbitoides Mantelli*, which is simply the prolongation of the West Indian Orbitoides limestone, and is thus the equivalent in time of the lower limestone of Malta [1].

The most elevated parts of the Bahamas and the whole outer girdle of the Antilles may be regarded with no small degree of certainty as isolated fragments of this great Tertiary 'plate' of Florida.

On the map of the Gulf of Mexico published by Hilgard it is easy to recognize the extension of these Tertiary deposits of Florida to the west and north [2].

To the east as to the west of the Mississippi, Palaeozoic and still older rocks crop out. To the east we see the southern termination of the Appalachians; there, as in so many other places, the middle and upper Cretaceous lie transgressively, covering the southern and western foot of the chain. The western group of Texas is also surrounded by the Cretaceous formation. Overlying the Cretaceous and like it horizontally stratified, follow the first stages of the Tertiary system. On Fig. 37 all its older members, together with the Vicksburg limestone, i.e. the Orbitoides limestone, are indicated by the sign $t_1$. This series comprises, as Heilprin has shown in Alabama, a lignitiferous group, the 'Buhrstone' with *Ostraea sellaeformis*, which lies at the base; the sandstone of Claiborne, which may be correlated by its mollusca with the 'calcaire grossier' of Paris; the

[1] Eugene A. Smith, On the Geology of Florida; Am. Journ. Science, 1881, 3rd ser., XXI, pp. 292-309.

[2] E. W. Hilgard, The Later Tertiary of the Gulf of Mexico, op. cit., 1882, 3rd ser., XXII, pp. 58-65, pl. iii; also by the same, On the Geological History of the Gulf of Mexico, Proc. Am. Assoc., 20th Meeting, Indianop., 8vo, Cambridge, 1872, pp. 222-236, and as a supplement to Humphreys and Abbot, Report upon the Physics and Hydraulics of the Mississippi River, 2nd ed., 4to, Washington, 1876, pp. 636-646, and F. V. Hopkins, Map in Ann. Rep. of the Louisiana State University, New Orleans, 1871.

white limestone (Jacksonian) containing the great Zeuglodont remains, and the Orbitoides limestone, which appears to be somewhat closely connected with the last named[1]. This series extends from the Rio Grande through Texas and Louisiana up the valley of the Mississippi, and is visible on the floor of the latter as far as Vicksburg; from this point it surrounds the Cretaceous zone on the east in a similar manner to that on the west, and is continued to the south towards Florida, as well as to the north across Georgia in the direction of the Atlantic coast.

Beginning at Pensacola, near the western boundary of the state of

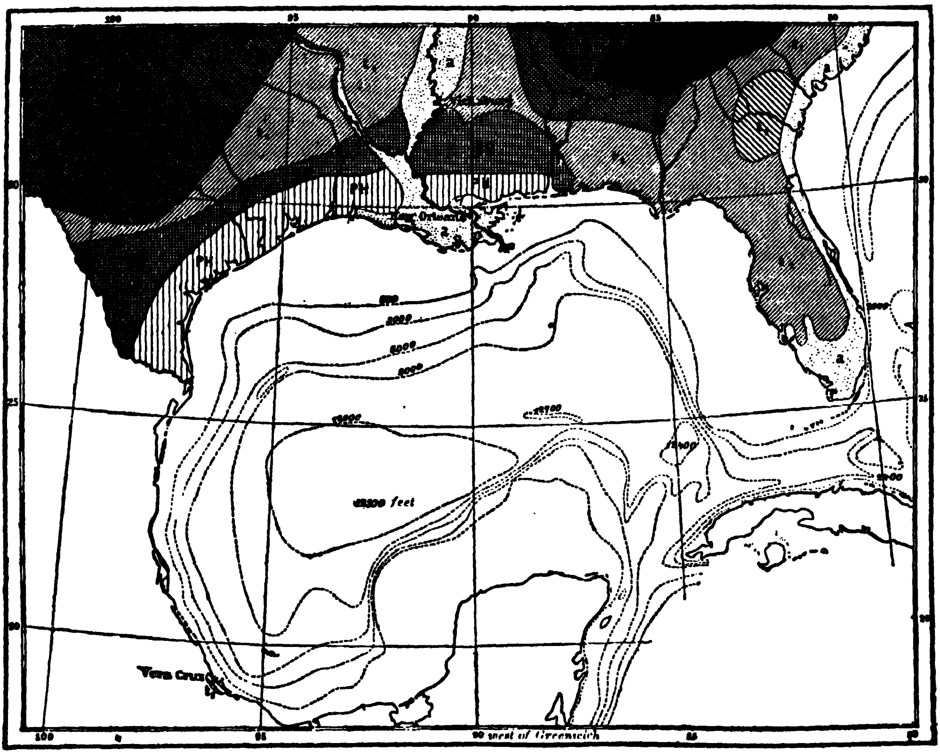



FIG. 87. *The Tertiary deposits on the north side of the Gulf of Mexico* (after Hilgard).
*arch*, Archaean; *p*, Palaeozoic; *cr*, Cretaceous; $t_1$, lower members of the Tertiary, including the bed of *Orbitoides Mantelli*; $t_2$, middle and upper Tertiary of the Atlantic Coast; *gg*, Grand Gulf series; PH, Port Hudson series; *a*, Recent deposits.

Florida, these Tertiary deposits reach the shore of the Gulf of Mexico, and their western limit on the mainland corresponds approximately to the course of an important steep submarine slope which marks the 100-fathom line west of Florida. We may notice as a remarkable fact

[1] A. Heilprin, Notes on the Tertiary Geology of the Southern United States; Proc. Ac. Nat. Sc. Philad., 1881, pp. 151-159.

that on the east of the peninsula, along the Atlantic coast, a further series of younger marine beds succeeds the Tertiary, while towards the west this is not the case. There on the contrary we find, extending westwards from Pensacola, across the valley of the Mississippi as far as Rio Grande, a zone of dark stiff clay, with thin intercalations of dark limestone containing gypsum and lignite, but with no other organic remains than traces of leaves and a tortoise. This is Hilgard's *Grand Gulf series* (*gg*, Fig. 37), which this author interprets as indicating a temporary cessation of communication between the gulf and the ocean. Overlying the Grand Gulf series is first a bright yellow drift sand, the *Orange sand*, and above this the marine beds of the *Port Hudson group*, which are of very recent date. They consist of alternating muds and lagoon deposits with sandy layers, in all more than 200 meters in thickness, and contain a marine fauna identical with that now existing.

It is therefore probable that during the time of the Grand Gulf series the separation of the Gulf of Mexico from the Atlantic Ocean by the Florida 'plate' was more complete than at present. We have already shown that the continuation of the 'plate' is to be found in the islands to the south, and indications are not wanting of the very recent date of their separation. Among these we may include the remains of a large, and only recently extinct, mammalian fauna found in the caves of the little island of Anguilla, while a more exact study of the existing fauna and flora throws still further light on the breaking up of the Tertiary 'plate.' Bland, for instance, has found that the terrestrial mollusca of the islands extending from Cuba to the Virgin Islands and Anguilla point to a connexion between Mexico and Central America; while those of Antigua and St. Christopher and the succeeding islands as far as Trinidad suggest a South American origin [1]. The fauna of the deeper parts of the Gulf of Mexico and of the Caribbean sea is, according to the latest researches of Alexander Agassiz, more closely allied to the deep-sea fauna of the Pacific than of the Atlantic [2].

From Florida there runs northwards, through Georgia, North and South Carolina, Virginia, Maryland, and New Jersey, a broad band of horizontally stratified Tertiary deposits which are but slightly raised above the present level of the sea and form the Atlantic border of the mainland. It termi-

[1] T. Bland, On the Geographical Distribution of the Genera and Species of Land Shells of the West Indian Islands, &c., Ann. Lyc. Nat. Hist., New York, 1862, VII, pp. 335-361; in addition: Notes relating to the Physical Geography and Geology of, and Distribution of Terrestrial Mollusca in, certain of the West Indian Islands, and On the Physical Geography of and Distribution of Terrestrial Mollusca in the Bahama Islands, op. cit., 1874, X, pp. 311-324; for mammals, see also M. F. de Castro, Pruebas paleont. de que la Isla de Cuba ha estado unida al Continente Amer., Bol. Com. Mápa geol. Esp., 1881, VIII, pp. 357-372.

[2] A. Agassiz, Origin of the West Indian (Caribbean) Echinoderm Fauna, in Reports of the Results of Dredging, &c.; Mem. Mus. Comp. Zool. Harvard Coll., 1883, X, pp. 79-94.

nates at about the 40th degree of latitude, and that part of the Atlantic coast which lies to the north of New York is not covered with Tertiary marine formations.

In Europe reef-building corals of Tertiary age are not of frequent occurrence except in the deposits of the south; this is also the case in America, and those deposits which occur north of Florida are characterized, like the horizontal Tertiary beds of northern Europe, almost exclusively by mollusca. According to the recent and valuable researches of Heilprin, three horizons may be distinguished here, all more recent than the Orbitoides limestone of Vicksburg. The first of these, the *stage of Maryland*, or the Atlantic lower Miocene, may be compared with a part at least of the first Mediterranean stage and the faluns of Léognan; the deposits of Virginia and a higher horizon in Maryland form Heilprin's *Virginian stage* or the Atlantic middle Miocene, and this may be regarded as the probable equivalent of the second Mediterranean stage. Finally the youngest deposits are those of north and south Carolina, the *Carolinian stage* or the upper Miocene of the west Atlantic [1].

Thus the general arrangement of the beds in this coastal border appears to be such that the older stages predominate to the north, the younger towards the south, i.e. towards Carolina. Their fauna is somewhat peculiar; in the younger strata the correspondence with the existing fauna of the west Atlantic increases; in those of Patuxent river, Maryland, Rolle thought so long ago as 1859 that he recognized a certain resemblance to the mollusca of Loibersdorf, i.e. of the first Mediterranean stage of Europe [2].

*The Atlantic Ocean.* Near lat. 40° N. the belt of American Tertiary deposits approaches the Atlantic coast. Further to the north there are no traces whatever of a Tertiary sea, neither in the United States, nor in Canada, nor beyond in the Arctic regions of North America. All the more recent formations which might possibly be regarded as such belong to the much later Champlain period. Equally in vain do we seek on the west coast of Norway, in Scotland, or Ireland for marine formations of the Tertiary period; they are not met with till we reach the southern half of the North sea.

It may perhaps be objected that these deposits have been destroyed by ice; but it is precisely in these northern portions of the Atlantic region that definite evidence of the existence of dry land during the middle of the Tertiary period has been preserved. This is afforded by the remains of a flora occurring in lignitiferous beds, which have been covered by basaltic lavas, and thus protected from subsequent destruction.

[1] A. Heilprin, On the Relation, Ages, and Classification of the Post-Eocene Tertiary Deposits of the Atlantic Slope; Proc. Acad. Nat. Sc. Philad., 1882, pp. 150–186.

[2] F. Rolle, Ueber die geologische Stellung der Horner-Schichten, Sitzungsber. Akad. Wiss. Wien, 1859, XXXVI, p. 81; also Heilprin, Proc. Acad. Nat. Sc. Philad., 1880, p. 33.

Such plant-bearing beds covered by basalt occur in county Antrim, in the north of Ireland; they are found also in the volcanic region of the Hebrides, and are thence continued further northwards. The Faeröes consist of two great horizontal sheets of basalt and tuff, which are separated by a bed containing coal and terrestrial plants. Similar formations also occur on Iceland, where they are known as 'Surturbrand,' and on the east coast of Greenland; in the basalt which extends from Kaiser Franz Joseph's Fjord to Shannon Island, intercalated layers with brown coal have been found by Payer in several places, particularly in the south part of Sabine Island[1]. These are repeated on the west coast of Greenland, as for instance on Disco Island, which has furnished material for some of the most instructive investigations of Oswald Heer, and yet further, even up to lat. 81° 45′ N., where, in Discovery Harbour and Robeson Channel, Feilden found Tertiary plants and obtained from the lignite deposits of these places the male flowers of *Taxodium distichum*, which have also been found in similar deposits on Cape Staratschin in Spitzbergen at the present day; this plant is a native of Mexico and the south of the United States[2].


FIG. 38. *Suderöe, the most southerly of the Faeröe Islands* (after J. Geikie[3]).

The wide distribution of these deposits, from Ireland and the Hebrides to the Faeröes, and across the Atlantic Ocean to Iceland, the east coast of Greenland, and even beyond, has been frequently regarded as a proof of the existence of a great continent, richly covered with vegetation, which

[1] J. Geikie, On the Geology of the Faeröe Islands, Trans. Roy. Soc. Edinb., 1880-1881, XXX, pl. xvi; A. H. Stokes, Notes upon the Coal found in Suderöe, Quart. Journ. Geol. Soc., 1880, XXXVI, pp. 620-626.

[2] Die zweite deutsche Nordpolfahrt, 1874, II; Toula, p. 477; Lenz, p. 486 et seq.; Heer, pp. 512-517.

[3] O. Heer, Notes on Fossil Plants discovered in Grinell-Land by Capt. H. W. Feilden, Quart. Journ. Geol. Soc., 1878, XXXIV, p. 67; also Etheridge, tom. cit., p. 569.

occupied the site of the present North Atlantic Ocean. To determine the exact chronology of these floras is an extremely difficult task; but it is probable that the existence of the continent or series of very extensive land areas was contemporaneous with a large part of our Mediterranean stages. The copious lava flows afford at the same time an indirect proof of the importance of the tectonic movements which affected these regions during the same period.

It is only in the far north that we again meet with marine Tertiary deposits. Toula, making use of Julius Payer's collections from several parts of the Greenland coast between 74° 30′ and 75° 30′, describes middle Tertiary quartziferous sandstone which on Hochstetter Foreland contains the remains of marine bivalves [1]. Nathorst subsequently brought back specimens from Eisfjord in Spitzbergen which show that these quartzite beds with marine mollusca extend as far as that point. According to Nathorst they are overlaid as well as underlaid by plant-bearing beds. In spite of the extremely bad state of preservation of the fossils T. Fuchs was able to distinguish among them such genera as Siliquaria, Pharella, Psammosolen, and Callista, which are at present quite foreign to the Arctic seas, and recall in a distant manner the age of our lower Mediterranean stages. It is at any rate certain that marine animals appear there which now characterize much more southerly regions. For further light we must await fresh discoveries [2].

Incomplete as is our present knowledge of the delimitation of this continent, or series of great islands, towards the north, still more uncertain is it as regards the south. The Azores, however, furnish one point of guidance. Here, too, there are volcanic rocks of Tertiary age; in the midst of the lavas and ashes, and beneath them, marine deposits appear. They occur on Santa Maria, the most southerly of the Azores, in lat. 37° N., then on Madeira and on Porto Santo, and, with the exception of a small patch in Madeira of more recent age, they belong, according to K. Mayer's investigations, exclusively to the Helvetian subdivision, that is, to the first Mediterranean stage. In Madeira these beds reach a height of 1,350 feet above the present sea-level [3].—

The east coast of the North Atlantic Ocean differs widely from the west.

When discussing the northern foreland of the Alps we distinguished within it three elements, namely, the Russian Platform, the Sudetes, and the region of the west European mountain cores. Among the latter we

[1] F. Toula, Zweite deutsche Nordpolf., p. 477.

[2] T. Fuchs, Ueber die während der schwedischen geologischen Expedition nach Spitzbergen im Jahre 1882 gesammelten Tertiär-Conchylien; Bihang till K. Svensk. Vet. Ak. Handl., 1883, VIII, Nr. 15.

[3] K. Mayer in G. Hartung, Geologische Beschreibung der Inseln Madeira u. Porto Santo, 8vo, 1864, p. 183 et seq., in particular pp. 276, 277.

included the mass of Bohemia, the Schwarzwald, the Vosges, the Central Plateau of France, and the Iberian Meseta. Their outlines are varied and irregular, and the older systems within them are folded; the middle and upper Cretaceous often extend over them transgressively; some of them are familiar to us as horsts, around and between which the Trias and Jurassic formations have subsided.

The Sudetes do not occupy nearly so large an area as the two other regions, and a glance at the geological map of Europe shows us that to the north of the Alps our continent may be divided, apart from the Sudetes, into two great regions. That on the east is the Russian Platform, which extends through the Baltic islands into the south of Sweden, where it terminates. That to the west consists of a group of great island-like masses of older folded rocks, between which areas of depression have sunk in. This is the region of the west European mountain cores; Norway, Scotland, Cornwall, Ireland, Brittany, and even the Ardennes, by their insular distribution, resemble, in spite of differences in detail, the mountain cores of the Alpine foreland.

The zigzag outlines of the north of Scotland, which owe their origin to certain great rectilinear faults extending to the sea-coast, have already (p. 206) been compared with the contours of the Bavarian Forest. Judd has shown that along these faults deeply sunken fragments of Mesozoic deposits have here and there been preserved from the general destruction. It is, he thinks, impossible to avoid the conclusion that the whole north and north-west of the British Archipelago, which is at present transformed by denudation into a rough mountainous land, was once covered like the south and south-east, if not entirely, yet at least to a great extent, with sedimentary deposits, which extended from the Carboniferous up to, and including, the Chalk [1]. We must therefore regard Scotland as a horst laid bare by denudation.

Much further to the north, on Andö, the most northerly of the Lofotens, a small and isolated relic of middle Jurassic occurs, which in all essential respects resembles the sunken fragments of Scotland [2].

With the single exception of the north of Spain, where the coast is formed by the outer border of a mountain chain, the whole west of Europe meets the Atlantic Ocean in mountain cores, all of them probably horsts. This is the cause of the excessively diversified outline of the coast; and as a consequence the Tertiary deposits do not form a continuous zone, as in the southern part of the United States, but extend into the continent as bay-like encroachments.

We have seen that in the Hebrides and the north of Ireland the Tertiary land floras are preserved beneath basaltic sheets. The coast of these

[1] Judd, Quart. Journ. Geol. Soc., 1878, XXXIV, p. 669.

[2] The latest description has been furnished by K. Pettersen, Lofoten og Vesteraalen; Archiv f. Mathem. og Naturvidensk., Kristiania, 1881, 97 pp. and geological map.

localities, as of the whole west of Ireland, is free from any trace of marine Tertiary deposits. The same is true of Cornwall. It is in the *Cotentin*, on the ridge of the old rocks of Normandy, a continuation of those of Cornwall, that there appears for the first time, as a sort of forerunner, a group of small patches of marine Tertiary deposits. These patches have been isolated on every side by denudation. We recognize here transgressive Cretaceous, marine deposits of the age of the 'calcaire grossier,' very doubtful equivalents of the first or second Mediterranean stage, and finally representatives of the English Crag, which belong to the period of the third stage. This remarkable spot also shows how widely the seas of the past may in certain cases have extended beyond those more or less enclosed basins, which are now filled by their sediments in continuous sheets.

The first of the important bay-like incursions of these deposits may be seen on the *lower Loire*. Here, too, as in the lower Mississippi, they overlie the transgressive Cretaceous formation; they also extend over the ridge of the mountain core of Brittany.

The second bay is that of the *Gironde*. This is bounded on one side by the edge of the mountain core of Brittany and of the Central Plateau, on the other by the outer margin of the Pyrenees; its situation therefore resembles that of the Tertiary land between the Bohemian mass and the Alps.

The third bay lies on the *lower Tagus*. Its Tertiary deposits are continued as isolated patches towards the south, reappear around Cape St. Vincent, and seem to be connected, on the other side of the Guadiana, with the deposits of the succeeding bay, so that here at all events we might speak of a girdle of Tertiary deposits bordering the Atlantic coast. In this case, however, the coast, at least in its general outline, seems also to correspond approximately to the contour of the Iberian Meseta. In the south, Tertiary deposits of marine origin lie on the Mesozoic border of the Meseta.

The fourth bay is that of the *Guadalquivir*. Its position resembles that of the Gironde; it is bounded on one side by the border of the Meseta, on the other by the outer margin of the Betic Cordillera.

The *Straits of Gibraltar* correspond, as we have seen, to the lateral fracture of a mountain chain.

Finally, the marine Tertiary formations of the Atlantic Ocean penetrate into the interior of Morocco.

The parts of the west coast of Europe enumerated above differ widely in tectonic importance. The patches in the Cotentin, the deposits of the lower Loire, as well as those of the Tagus, and those along the Portuguese coast around Cape St. Vincent, we consider to be parts of the old Atlantic coast or of the Atlantic sea-floor. The depressions of the Gironde and the Guadalquivir, on the other hand, correspond to the course of two great

mountain chains and conceal the junction between these and their foreland. However great may be the significance of the Straits of Gibraltar as regards the existing physical geography of our continent, yet they do not enter into the scheme of its general structure, and from this point of view may be regarded merely as an accident of quite subordinate interest.

The close correspondence between the littoral formations of the Atlantic and the deposits of the Mediterranean compels us from the outset to assume a free communication during the period they represent between both seas, and we naturally look for it on the two lines of greatest tectonic importance, the Gironde and the Guadalquivir.

Our further study will be greatly facilitated if we now cast a hasty glance over the younger Tertiary deposits of the north-west of Europe. A separate treatment of this subject is all the more justified since the Mediterranean type is only represented in this region in a modified form.

Around the southern part of the North Sea remains of flat-lying beds are to be seen, which represent the period of the first and probably of the second Mediterranean stage. The outlines of the areas over which they are at present distributed depend, however, solely on the degree of denudation to which these low lands have since been exposed. They form, as appears from the investigations of Dumont and Beyrich, a broad arc open to the north-east, which extends from the island of Sylt towards Antwerp, and includes the lower course of the Elbe, the Weser, the Ems, the Rhine, and their estuaries, as well as the mouth of the Scheldt [1]. Of this great curve the eastern and western parts are still fairly complete, but the southern part, to which the marine deposits of Osnabrück and Bünde are to be assigned, is full of gaps; still the position of these denudation remains is such that they may be easily recognized as a series of successive margins to a basin. The estuaries of the great rivers, which flow into the North Sea, lie at the bottom of this basin, which thus coincides with an existing depression of the land.

No prolongation of this great arc is found however in England. Hitherto no marine deposits of the first and second Mediterranean stage have been recognized anywhere in Great Britain; nor are they known with any degree of certainty in the Cotentin, and the valuable investigations of Vasseur in the valley of the Loire leave little room for doubt that they are not represented there, or at the most only in a highly incomplete manner and by their very uppermost beds [2].

Near Bovey Tracey in Devonshire, on the ridge of the old rocks which finds its continuation in Brittany, plant-bearing beds occur which

[1] Beyrich's general map in the Abhandl. Akad. Wiss. Berlin, 1855, still forms the basis for a study of this region.

[2] G. Vasseur, Recherches géologiques sur les terrains tertiaires de la France occidentale; Ann. des Sciences géol., 1881, XIII, pp. 1-432, and maps.

Oswald Heer compares with those previously mentioned as occurring at Antrim in Ireland: he assigns them to the Aquitanian stage and correlates them with the deposits of Salzhausen in the Wetterau, the age of which cannot be greater than the lowest horizon of the first Mediterranean stage, and may even be a little less. We may thus with Ramsay see in these deposits a fresh proof of the regression of the sea during the Miocene period, and of the wide extension of a continent or series of large islands over the site of the existing North Atlantic Ocean [1].

It is very different in the case of the later deposits. The various subdivisions of the Belgian and English Crag may be regarded as the chronological equivalent of the third stage. They appear to the west at the bottom of the great basin which surrounds the North Sea on the south, cross from Antwerp to Norfolk and Suffolk, lie transgressively in the low lands of the east of England, in particular on the Eocene London clay, and appear, also as clay with *Nassa prismatica*, as encroachments in the Cotentin and the bay of the Loire [2].

Two facts are here especially worthy of note.

First, we may observe that the English Crag contains a large admixture of northern species. They increase in number in the upper beds; but even at the base of the lowest division, the Coralline Crag, Prestwich came across a great block of porphyry, which he regarded as a proof that transport by means of ice had already taken place in these latitudes at the beginning of this period. If, therefore, in the case of the Mediterranean, the introduction of Arctic species is to be regarded as indicative of the beginning of the fourth stage, we must either admit that such species appeared earlier in the north or else place the whole of the Crag in the fourth stage.

Secondly, the Crag deposits, both of England and Belgium, in spite of their horizontal stratification and their trifling height above the present sea-level, show distinct signs of repeated fluctuations of the strand-line. Owing to the horizontal position of the strata large areas must have been laid dry by these oscillations. In Suffolk the Red Crag lies in eroded valleys of the older White or Coralline Crag, and also surrounds blocks of the latter, which have been left standing like islands.

The Eocene deposits play a prominent part in the structure of the

[1] W. Pengelly, The Lignites and Clays of Bovey Tracey, Devonshire, Phil. Trans. 1863, CLII, pp. 1019-1038, 3 pl., and O. Heer, On the Fossil Flora of Bovey Tracey, tom. cit., pp. 1039-1086, 17 pl.; further, Ramsay, Physical Geography and Geology of Great Britain, 8vo, 1878, pp. 259, 354.

[2] From the abundant literature on this subject I will only mention J. Prestwich, On the Structure of the Crag-Beds of Norfolk and Suffolk, Quart. Journ. Geol. Soc., 1871, XXVII, pp. 115-146, 325-356, and 452-496, and E. Van den Broeck, Esquisse géologique et paléontologique des dépôts pliocènes des environs d'Anvers, Mém. de la Soc. Malacol. Belg., 1874, IX, pp. 83-371.

south-east of England, and they appear not only in Belgium but also in the Cotentin and in the islands at the mouth of the Loire, which are formed by the Calcaire grossier; in the Oligocene period again the sea advanced in a still more extensive transgression, forming a long gulf extending from the Atlantic Ocean to Rennes, and spreading its deposits, as the sands of Fontainebleau, far beyond the limits of the Paris basin; on the other hand, during the first Mediterranean stage we observe a regression of the waters as far as the Loire. Later still many districts which had hitherto lain dry were again covered by the sea, and signs of a cold period steadily growing more distinct make their appearance.

*Guadalquivir.* The great mountain cores of western and central Europe bear on their shoulders large patches of fresh-water deposits which prove that these heights were not covered during the various extensions of the Mediterranean we are about to discuss. On the summit of the Spanish Meseta middle Tertiary fresh-water limestones and marls, sometimes accompanied by gypsum, extend in horizontal beds and still cover a very considerable part of the surface of the peninsula. In like manner there appear on the Central Plateau of France, chiefly in the upper basin of the Loire, Tertiary deposits of various age, which have all been formed in fresh water. These are accompanied by a diversified series of volcanic rocks. So too on the Bohemian mass, at the foot of the Erzgebirge, we see, similarly accompanied by volcanic rocks, a series of coal-bearing Tertiary deposits, which have been formed exclusively in fresh water; the mammalian remains which these enclose leave no room for doubt that chronologically they also include the first and second Mediterranean stage. In the same way lignitiferous Tertiary beds appear in the south of Bohemia; the age of these, however, is no doubt somewhat more recent.

Large regions may thus be distinguished at once as forming part of the ancient continent. On the borders of these regions and to the south of them occur the marine deposits which we now propose to study; sometimes, but only very rarely, they present themselves as true littoral deposits. Sometimes they rest horizontally against steep mountain slopes, either as patches isolated by erosion, or again as sheets underlying broad plains, but frequently also they are thrust against the outer zones of the mountain chains, and are exposed as the basset edges of erect strata, thus bearing witness to the remarkable fact that our great existing mountain chains are in large part of so recent an origin as to have been once submerged by these later extensions of the Mediterranean Sea.

We now must enter into a multiplicity of detailed observations in order to discover the main features of the successive extensions of the Mediterranean.

In the south-west of Spain a large tract of marine deposits, which

correspond to the first, second, and third Mediterranean stages, extends into the land from the Atlantic Ocean, and at the place where the most recent of these stages emerges from the sea there stand, near the town of Huelva, on an ever memorable spot, the ruins of the Franciscan monastery, Nuestra Señora de la Rabida, where on August 3, 1492, Christopher Columbus embarked in search of a new world. Here we will begin.

The arrangement of the Mesozoic strata in the south of Portugal makes it probable, as we have already said, that the existing outline of the continent corresponds to that of the Meseta. Ribeiro's map shows a Mesozoic girdle, running from west to east, through the whole of Algarve to the mouth of the Guadiana. Near Ayamonte a last fragment of Trias is to be seen, and the edge of the Meseta then advances eastwards into the interior, while to the south the Tertiary bay opens over Huelva, Xeres, Cadiz, and Vejer de la Frontera. This is the same bay as that which I have already spoken of as the bay of the Guadalquivir.

Gonzalo y Tarin has shown how the marginal belt of marine Miocene beds, characterized by great oysters and large species of the genus Clypeaster, leans against the foot of the Meseta, while more to the south younger beds with *Voluta Lamberti*, representing the third Mediterranean stage, occur and extend past Huelva and La Palma towards the province of Seville [1].

The base of the first stage is represented by the Orbitoides limestone, which MacPherson discovered on the margin of the Meseta in Seville [2], while Mallada has traced the Calcaire grossier containing large oysters and Clypeaster along the valley of the Guadalquivir, across the province of Cordoba, as far as Jaen [3]. Verneuil long ago recognized isolated patches of the same beds in the upper parts of the valley, even as far as the vicinity of Alcaraz in western Murcia, and concluded from this, as early as 1853, that in the Tertiary period an arm of the sea must have extended across the present continent, and separated the Sierra Nevada, together with the Sierra de la Sagra, the Sierra de Segura, and the mountains of Jaen, from the Meseta, which was then covered with fresh-water lakes [4].

[1] Gonzalo y Tarin, Descripcion geológica de la Provincia de Huelva; Bol. Com. Mápa Geol. Esp., 1878, V, pp. 75, 81, 87.

[2] MacPherson, Provincia de Sevilla, op. cit., 1879, VI, p. 252.

[3] L. Mallada, op. cit., 1880, VII, p. 48.

[4] De Verneuil et Collomb, Coup d'œil sur la constitution géologique de quelques provinces de l'Espagne, Bull. Soc. géol. de Fr., 1853, 2e sér., X, pp. 78, 79; and by the same, Géologie du Sud-Est de l'Espagne, op. cit., 1865, 2e sér., XIII, p. 716 et seq. D'Archiac pointed out as early as 1849 that the Castilian Plateau, with a mean height of 682 meters, and the tableland of Auvergne, of only 339 meters, had both remained above the level of the sea which surrounded them: Histoire des progrès de la géol., II, 2e partie, p. 841.

These marine deposits, however, frequently extend either as large sheets or small patches into the mountains lying to the south of the Guadalquivir. Among the fossils collected by Drasche between the city of Granada and the Sierra Nevada, close to the foot of the mountains, T. Fuchs has recognized a Pecten characteristic of the Schio beds, that is, the lowest part of the first stage, while in the Lithothamnium limestone of Escuzar *Pecten Zitteli* is found, which is now regarded as belonging to the base of the second stage [1].

According to Gonzalo y Tarin these deposits have taken part in the great mountain foldings of the district, although they lie transgressively on the older rocks. The distribution of the patches shows that they once extended over the whole region of the Alpujarras in the south-west of the Sierra Nevada, and they also occur near Ugijar in the south of the high mountains [2].

Verneuil observed them up to a height of 1,200 meters.

We must, therefore, conclude that the Atlantic and the Mediterranean were united through the bay of the Guadalquivir during the existence of the first, and probably also of the second stage. The northern shore may be traced along the southern foot of the Meseta, far inland from the sea; but the southern margin of the bay cannot be determined, since subsequent mountain movements have completely altered the structure of the land. There can however be no doubt that parts of the existing Cordillera, to the south of the Guadalquivir, still formed the sea floor, and the communication between the two seas was established in all probability not only across the upper course of the Guadalquivir and the adjacent parts of Murcia, but also over that region which is now occupied by the Alpujarras, as well as other places.

At the same time we must not overlook the fact that repeated oscillations of a subordinate nature are indicated by the intercalation of fresh-water deposits within the marine series, as, for instance, in the south part of the valley of the Geniel (Granada). The same phenomenon recurs along the east coast, for instance near Barcelona, where the greater part of the marine deposits probably belong to the second stage.

At the time of the third stage a communication of the ocean with the Mediterranean along the line of the Guadalquivir did not exist or has not yet been recognized [3].

*Gironde.* The great low-lying area which proceeds from the Atlantic

[1] R. v. Drasche, Geologische Skizze des Hochgebirges der Sierra Nevada, Jahrb. geol. Reichsanst., 1879, XXIX, pp. 113, 115; also Silvertop, Proc. Geol. Soc., 1834, p. 216; Ansted, op. cit., XV, p. 585.

[2] Gonzalo y Tarin, Provincia de Granada; Bol. Com. Mápa Geol. Esp., 1881, VIII, p. 78 et seq.

[3] Op. cit., p. 83; further, I. Gombau and A. M. Alcibar, Provincia de Tarragona, op. cit., 1877, IV, p. 237.

between the northern border of the Pyrenees and the estuary of the Gironde resembles that of the Guadalquivir in the chief features of its structure. Here, as there, the northern edge is formed by the southern slopes of an old mountain core, there of the Iberian Meseta, here of the Central Plateau of France; and here, as there, the southern boundary is furnished by the folded foot of a mountain chain. Here, again, as there, it is utterly impossible to reconstruct the southern shore of the ancient ocean; and unfortunately in the Gironde the marine deposits which we have to trace lie so flat, are of such a trifling thickness, and have suffered so much from denudation, that we can only make the vaguest conjectures even as regards the north.

Let us first consider the immediate neighbourhood of Bordeaux.

As early as 1848 it was well recognized by Raulin, and the fact was confirmed by Tournouër in an admirable work published in 1862, that the arrangement of the various marine Tertiary beds in this district is such that we meet successively older beds as we approach the Central Plateau, and more recent as we proceed towards the ocean. Thus the older Molasse lies in the valley of the Dordogne and the Oligocene 'calcaire à astéries' chiefly in the region of the Garonne; the older divisions of the Mediterranean faluns, so rich in mollusca, find their typical development to the south-west of the city of Bordeaux; but the youngest division presents its most characteristic exposures far out in the plain, in the midst of the sand of the Landes, near Salles, on the river Leyre [1].

The Oligocene deposits resemble more nearly those of the southern Alps than of the lower Loire and the Seine; they preserve still to a certain degree south European characters, and conclude with fresh-water beds. The marine deposits which overlie them are also separated from each other by intercalated fresh-water beds. Above the 'calcaire à astéries' lies the first fresh-water horizon; then follow the marine faluns of Bazas and Merignac; another fresh-water horizon is followed by the marine faluns of Léognan, this again by a fresh-water horizon, to which finally succeeds the youngest faluns, those of Salles.

The faluns of Bazas and Merignas should perhaps be correlated with the lowest part of the first stage; the correspondence of the faluns of Léognan with the deposits of Gaudendorf and Eggenburg, i. e. with the middle and upper members of the first stage, was pointed out many years ago by M. Hoernes, and in like manner T. Fuchs has demonstrated the complete agreement of the mollusca of the faluns of Salles with those of the deposits of the second Mediterranean stage in the depression of the Vienna basin [2].

[1] Tournouër, Note stratigraphique et paléontologique sur les faluns du département de la Gironde; Bull. Soc. géol. de Fr., 1862, 2e sér., XIX, p. 1038.

[2] T. Fuchs, Der 'Falun von Salles' und die sogenannte 'jüngere Mediterranstufe'

If we leave this region and turn inland towards Lot-et-Garonne and Gers, we shall find the marine deposits rapidly thinning out, while the isolated extra-marine intercalations of the neighbourhood of Bordeaux continuously increase in importance towards the south-east, and finally, as has been shown in detail by Linder, are superposed upon each other, retaining their individuality, although no longer separated by marine beds [1].

Some patches of marine deposits of the second stage which have escaped destruction still occur, however, near Sos and Eauze, not far from the boundary of the two departments referred to above, and about 120–130 kilometers distant from the sea [2]. Still further to the south we find the continuation of these beds at the foot of the Pyrenees. There to the east of Bayonne they are arranged in the same way as in the neighbourhood of Bordeaux, so that the younger members of the series succeed each other in the direction of the plain. The older Tertiary deposits are followed by the faluns of Gaas, which are the equivalents of Castel Gomberto; the first Mediterranean stage is represented by the faluns of St. Paul, north of Dax, and St. Avit near Mont de Marsan, and these are succeeded by the faluns of Saubrigues and St. Jean de Marsac, which belong to the second stage, and are consequently the continuation of the faluns of Salles, Eauze, and Sos [3]. East of these localities the foot of the Pyrenees is covered with detritus.

The marine deposits disappear towards the interior; in the department of Gers and towards Toulouse fresh-water deposits broaden out; notwithstanding the existence of the first and second stages near Bordeaux as well as west of Bayonne, and notwithstanding their evidently deep penetration into the land, we are precluded, by reason of the great development of the fresh-water deposits which continues to the final exclusion of the marine, from assuming for the present an ancient communication over this area between the Mediterranean and the Atlantic.

Many years ago Tournouër regarded the line of the Guadalquivir, the

des Wiener Beckens; Verhandl. geol. Reichsanst., 1874, pp. 105–111. Even if it should be found that the faluns of Bazas-Mérignac correspond to the deposits of Molt, nevertheless a characteristic member of the first stage at Vienna would be wanting in the Gironde, namely the beds of Loibersdorf with *Cardium Kübecki*.

[1] Linder, Des dépôts lacustres du vallon de Saucats, Actes de la Soc. linn. de Bordeaux, 1872, XXVII, pp. 451–525; also earlier, R. Tournouër, Sur l'âge géologique des mollasses de l'Agenais, Bull. Soc. géol. de Fr., 1869, 2e sér., XXVI, pp. 983–1023.

[2] V. Raulin, Aperçu sur l'orographie, la géologie et la hydrographie de la France, in Dechambre, Dict. encycl. des sciences médic., 8vo, Paris, 1879, p. 349, and elsewhere.

[3] J. Delbos, Essai d'une description géologique du bassin de l'Adour, 4to, Bordeaux, 1854, and elsewhere; for the age of Saubrigues see also Benoist, L'étage Tortonien dans la Gironde, Actes Soc. linn. Bordeaux, 1878, XXXII, pp. lxxxv–xc.

*Andalusian straits* as he called it, as the sole channel of communication between the ancient Mediterranean and the ocean, and this view has received confirmation from later researches.

This result is the more remarkable since in the region of the Loire, to the east of the older rocks of Brittany, a vast lobe of marine deposits belonging to the second stage occupies the land. These are the faluns of Touraine, which extend beyond Blois, while the region of the Seine was not invaded by this extension of the sea[1]. The faluns of Pont-Levoy in Touraine correspond with those of Salles and Saubrigues, but the communication of this part of the sea with the ocean was not by way of the north, the east, nor the lower Loire, but probably over Poitiers. No doubt a very extensive erosion of these readily destroyed deposits has taken place.

The bay of the Gironde must thus be regarded, not as an ancient strait of the Mediterranean, but solely as an Atlantic gulf, from which the sea repeatedly retired, only to return to it again. The first stage is represented by marine deposits; the second stage extended over a very large area, and it may even be supposed that at this time the sea reached as far as the Loire. Deposits of the third stage have not been observed in this region.

*Rhone.* As the valley of the Guadalquivir and that of the Loire opened into the waters of the Atlantic, so the present valley of the Rhone opened into the western Mediterranean. Near Montpellier a diversified series of younger Tertiary deposits rests against the southern border of the Central Plateau, and marine deposits of the first, second, and third stage penetrate from the mouth of the Rhone far north into the land. A knowledge of this region is of great importance in the study of the history of the Mediterranean, and we possess, apart from older works, a series of excellent monographs by F. Fontannes, which afford us a clear insight into the subject[2].

It must be observed first that the valley of the Rhone below Lyons, which might more correctly be termed the valley of the lower Saone, shows the same features in its general structure as those which we have already met with on the Guadalquivir and the Gironde. Here again one side of the valley is formed by an ancient mountain core and the other by the folded border of a mountain chain, in this case the Alps. But it must be observed here that the deposits of the first, and, according to Fontannes' sections, also of the second stage, although to a great extent

[1] R. Tournouër, Sur les dépôts d'eau douce du bassin de la Garonne, correspondant au calcaire de Beauce et aux sables de l'Orléannais, Bull. Soc. géol. de Fr., 1867, 2ᵉ sér., XXIV, in particular p. 486; and by the same, Sur les lambeaux du terrain tertiaire des environs de Rennes et de Dinan, op. cit., 1868, 2ᵉ sér., XXV, p. 386 et seq.

[2] F. Fontannes, Études stratigraphiques et paléontologiques pour servir à l'histoire de la période tertiaire dans le bassin du Rhône, 7 parts, Lyons and Paris, 1875–1881.

resting transgressively on *patches* of Cretaceous, have yet been involved in the movements of the outer border of the Alps. Towards the Alps they are steeply upturned, and in some places even inverted[1], and we are thus deprived of the data by which we might determine the eastern shore of the first and second stage. As regards the third stage, the case is different, as will appear directly.

About half-way between Lyons and the sea, near Montélimart, the convex curve of the Alps approaches nearest to the marginal fracture of the Central Plateau, and precisely at this place there rises a long ridge of Cretaceous rocks, bordered on the east and west by Tertiary deposits. This ridge separates the province of Dauphiné in the north from that of Provence in the south. The latter is interrupted by the rounded summits of the Cretaceous mountains.

All three Mediterranean stages extend to the north across the gorge of Montélimart and beyond it. They rest on fresh-water beds, the uppermost of which may possibly belong to the first stage. Upon these follows a thick series of marine beds, which Fontannes terms the 'Helvétien' or 'Groupe de Visan.' This group includes the equivalents of Léognan and the first Mediterranean stage, but its highest beds, the marls and sands of Tersanne, Visan, and Cabrières, represent the second stage. This highest member presents two different developments. In the south, e.g. near Cabrières by Mont Luberon, it is a purely marine deposit, distinguished by *Ancillaria glandiformis, Cardita Jouannetti,* and other characteristic species, and is compared by Fisher and Tournouër to the faluns of Salles, while T. Fuchs and Fontannes both recognize a remarkable resemblance to the beds of Grinzing[2]. It is therefore certain that this horizon belongs to the second stage, and that the fresh-water deposits, which elsewhere are intercalated between the first and second stages, are here unknown. In the Bas-Dauphiné, on the contrary, and to the north of it, a deposit appears, which contains at Tersanne (Drôme) a fairly large number of marine species, but further north furnishes, besides numerous Helices, only a single species of a smooth-shelled Nassa, *N. Michaudi.*

The second stage is followed by fresh-water limestone; above it appear red clays with the rich mammalian fauna of Cucuron.

The next beds have been deposited under very different conditions. They are separated from the preceding by a period of erosion, when the valleys within which they lie were excavated; they have not shared in the folding movements of the Alps.

The first member of this second group consists of the remarkable fresh-

[1] Fontannes, op. cit., VI, Le bassin de Crest, Fig. 13, p. 47.

[2] C. Fischer et R. Tournouër, Invertébrés fossiles du Mont Léberon (from Gaudry, Fischer et Tournouër, Animaux fossiles du Mont Léberon), 4to, Paris, 1873, p. 152; Fontannes, Études, IV, p. 59; and in particular Fuchs, Boll. Com. geol. d'Ital., 1879, pp. 17–19.

water beds of Bollène, with Melanopsis, Cardium, and Congeria; their resemblance to the extensive fresh-water deposits of eastern Europe was first pointed out by K. Mayer. Then follow the marls with *Nassa semistriata* as the marine representatives of the third stage, after these again land and fresh-water deposits. The beds with *Mastodon avernensis* are still more recent.

Thus the valley of the Rhone also exhibits a long series of alternating marine and extra-marine strata. The limit between the first and second stages is not, as in so many other places, marked by an extra-marine intercalation; towards the north, however, the second stage is only indicated by the littoral beds with *Nassa Michaudi* and land-shells. Between the second and third stage, on the other hand, so important a regression of the sea occurred, that the excavation of valleys followed, and it is possible that great tectonic changes along the border of the Alps took place in this period. The Congeria beds of Bollène are the first which were deposited in these new valleys. I must, however, confess that I am still in some doubt as to the position occupied in this classification by the mammaliferous red clay of Cucuron; it appears to be neither a marine nor a purely fresh-water formation, but, as in many other places, a sort of *Terra rossa*, which is in the main subaerial, the action of streams, if concerned at all, being restricted to its final accumulation; it is the residue left by solution on limestone plateaux which have been exposed for a long time to the action of the atmosphere. Of this nature are the red clays of the Karst, the red breccias in the joints of the limestone of many islands in the Mediterranean, and probably also the red clay of Pikermi, near Athens [1].

The three stages of the Mediterranean penetrate into the land in the following manner:—

The first stage follows the margin of the Alps, takes part in the folding, but becomes horizontal at a little distance from the mountains. It passes through Chambery and the Lac de Bourget into Switzerland, and finds its direct continuation in the marine Molasse of the Swiss Alps.

The second stage also appears to take part in the mountain foldings, but like the first lies flat at a little distance from the Alps. To the north it is only represented by a littoral deposit rich in land-shells, and containing *Nassa Michaudi*; it extends northwards, together with its substratum, in small plateaux divided by erosion, as far as the great bend of the Rhone, near Lyons. But it does not pass as a marine deposit into the Swiss Alps.

The course of the coast at the time of the third stage has been traced

[1] The suggestion of Fontannes (IV, pp. 61, 62 in particular) that the ossiferous layer of Cucuron is older than the beds with *Nassa semistriata* (third stage) appears to me to be perfectly correct and in accordance with all that I have observed elsewhere with regard to beds of this kind.

in great detail by Fontannes through the whole of the south of France[1]. Near Perpignan at the eastern end of the Pyrenees it bites like a bay into the land, extends through Narbonne and Bezières, passes around the promontory of Frontignan and Cette, is then determined by the Cretaceous ridges of Montpellier and Nîmes, and finally penetrates deep into the land near Avignon. The marine deposits of this stage are known as far as the Péage-de-Roussillon, south of Vienne. The northern part of the gulf is narrow and lies, as has already been observed, in the hollows excavated in the deposits of the first and second stage. The beautiful sections drawn by Fontannes across the already mentioned Cretaceous ridge of Montélimart, which extend from the Alps to the border of the Central Plateau, show the following structure: between the Alps and this ridge, the first and second stage are bent together in a synclinal, while on the other side of the ridge, between it and the edge of the Central Plateau, lie the horizontal beds of the third stage through which flows the existing river Rhone[2].

The east side of the gulf in the third stage was indented by several bays as in the valley of the Durance; it reached the present coast near Martigues.

We now return to Chambery and enter the region of the Alps. Over a great stretch of country we encounter only the first Mediterranean stage, represented by marine deposits; this fact may serve to introduce another method of treating our subject. We will no longer compare whole regions according to the distribution of the three stages in them, but will now attempt to trace each single stage through the several areas in which it occurs.

*The first Mediterranean stage.* The first stage not only appears in the outer zone of the Alps, but also in many of the great longitudinal valleys of the Jura, and has been involved, together with the overlying upper fresh-water Molasse, in all the great and regular foldings of this chain. This stage here bears the name of upper marine Molasse or *Muschelsandstein*. It occurs, for example, in the Jura of Waadtland near Locle and La Chaux de Fonds and contains rolled fragments derived from the lower Cretaceous, a proof that a part of the Jura had already risen above the sea before this period[3]. Nevertheless, as a result of folding, it attains near La Chaux de Fonds a height of 1,040 meters. In the longitudinal valleys of the Bernese Jura it is accompanied by Nagelflue, the pebbles of which have been derived from the Vosges or the Schwarzwald[4].

The thickness of this stage within the Jura is, however, inconsiderable, and many circumstances testify to the proximity of the coast.

[1] Fontannes, Note sur l'extension et la faune de la mer pliocène dans le sud-est de la France, Bull. Soc. géol. de Fr., 1862, 3e sér., XI, pp. 103–141.

[2] Fontannes, Études, VI, Le bassin de Crest, pl. A, B, C.

[3] A. Jaccard, Description géologique du Jura Vaudois (Matér. p. l. carte géol. de la Suisse, VI, 1869), p. 106 et seq.

[4] J. B. Greppin, Le Jura Bernois (Matér., VIII, 1870), p. 176.

Near Chambery the marine Molasse lies, according to Studer, on the lower fresh-water Molasse; at the Lac de Bourget it rests with a steep dip against the Rudistes limestone, as is also the case near Seyssel [1]; at the Perte du Rhône itself, Renevier describes it as lying horizontally on the Cretaceous [2].

We are now in the interior of the Molasse region of Switzerland. The marine Molasse lies here on the lower fresh-water Molasse, which includes a marine or brackish-water deposit, comparable in age with the faluns of Bazas near Bordeaux; above the marine Molasse lies the upper fresh-water Molasse. The structure of this region has often been remarked upon. The beds of the Molasse are arched up along the front of the Alps, but at a little distance from the mountains they become horizontal. The marine Molasse extends along the whole length of 'the anticlinal of the Molasse,' leaves Switzerland near Bregenz, and is continued in the direction of Kempten in Bavaria. Here, too, the northern limb lies horizontally and is continued across the Lake of Constance towards the edge of the Swabian Alps.

In the region we are about to describe we see, as in so many previous cases, on one side the forward thrust border of a mountain chain, and on the other, first the fault of the Danube, and then the southern boundary of the Bohemian mass. We have thus a southern (or sub-Alpine) zone and a northern zone of marine Molasse, while the more recent formations cover more or less completely the intervening plain; in this case again the southern zone evidently cannot be regarded as a coast-line.

The southern zone, according to Gümbel's observations, runs from Bregenz through Scheffau, Kempten, Peissenberg, and finally Traunstein, into the immediate neighbourhood of the Salzach, keeping an almost constant distance from the limestone Alps [3]. It does not appear to cross into Austria. We have thus established that from Mont Luberon on the Durance (an east-to-west offshoot from the curve of the Alps), up the valley of the Rhone past Montélimart, then past Chambery through the whole of Switzerland, the Vorarlberg, and the whole of Bavaria, that is, from the Durance to the Salzach, marine deposits of the first Mediterranean stage have been involved in a forward movement of the folded border of the great Alpine chain, which thus itself, at least in its outer zone, stands on a space which once formed part of the Mediterranean Sea.

The northern flat-lying zone of the marine Molasse rests, not on the

[1] B. Studer, Geologie der Schweiz, II, p. 434.

[2] E. Renevier, Mémoire géologique sur la Perte du Rhône; Denkschr. Schweiz. Natf. Ges., 1855.

[3] Gümbel, Geognostische Beschreibung des Königsreiches Baiern, I, p. 756 et seq.

lower portions of the Tertiary formations, but on much older rocks, chiefly the Jurassic limestone of the Swabian Alps. It is the continuation of the zone which is known in Switzerland as the 'sub-Jurassic' marine Molasse. On the slopes of the Randen it may be observed, according to Schill, at a height of more than 800 meters[1]; in the adjacent volcanic region of the Höhgau it has been subjected to many disturbances, thence it proceeds far to the north-east following approximately the foot of the Alps.

The continuity of its course is often concealed by erosion or by superficial deposits, but it may be distinctly followed up to the edge of the Bavarian Forest, where it lies sometimes upon Archaean rocks, sometimes on the patches of Jurassic in the neighbourhood of Passau, as, for example, at Ortenburg, where it is distinguished by a great abundance of fossils[2]. A series of patches mark its continuation along the margin of the Bohemian mass, near Linz, Wallsee, Mölk, Wiedendorf near Krems, Grübern, Meissau, Eggenburg, until its last traces disappear near Unter-Nalb, not far from Retz.

Thus this zone also is known to extend over an extremely great distance, from Switzerland almost as far as the place where the river Thaya makes its exit from the ancient mountains into the plain (v. p. 215).

Towards the east its diversity increases to some extent. In the west, as we have already observed, marine sands rest as a rule directly on the older rocks; near Linz the zone is chiefly represented by white sand, containing remains of Squalodon and other marine mammals; but near Mölk this white sand is underlaid by clay containing *Cerithium margaritaceum* and *Ostrea fimbriata*, accompanied by carbonaceous beds, which recall the brackish-water beds underlying the southern zone in the sub-Alpine region of Switzerland and Bavaria[3].

Near Meissau in Lower Austria a true littoral formation occurs on the outer slopes of the Mannhart mountains, and, as M. Hoernes observed many years ago, sea-acorns may still be seen attached to their wave-worn, rounded, granite summits. To the west of Meissau, near Horn, a large patch of these deposits is let down into the older rocks: this is the so-called 'basin of Horn,' the structure of which exhibits the greatest diversity and complexity. The substratum consists here of the brackish-water beds of Molt containing *Cerithium margaritaceum*; these correspond to the coal-bearing deposits of Mölk. They are covered by the sand of Loibersdorf, con-

[1] J. Schill, Die tert. u. quart. Bildungen des Landes am nördl. Bodensee u. im Höhgau, 8vo, Stuttg., 1858, pp. 33, 102, et passim.

[2] Gümbel, op. cit., II, p. 784.

[3] F. Posepny, Oligocäne Schichten bei Pielach nächst Melk; Jahrb. geol. Reichsanst., 1865, XIV, Verhandl., p. 165. I have also met with fragments of Cyrena at this place.

taining the great *Cardium Kübecki*, and the other types already mentioned as recalling American species; a horizon of trifling thickness and containing many Oligocene species has been recognized as far as Transylvania, but up to the present has not been observed in western Europe. The next horizon is that of Gauderndorf, which is strictly comparable to the marine Molasse of St. Gallen, and on this rest the more littoral formations of Eggenburg and Meissau.

The southern zone terminates on the Salzach, while the northern zone extends nearly as far as the Thaya.

Some traces of the first Mediterranean zone occur still further to the north, but they are isolated and not distinctly characterized. The only certain indication of its presence on the outer side of the Carpathians occurs not far from Mautnitz, near Seelowitz, in the north of Moravia[1], where the horizon of Gauderndorf and perhaps that of Eggenburg are to be seen. In the beds overlying the Carboniferous region of Ostrau the former of these horizons also appears to be represented, and beneath it lie basaltic tuffs with great marine shells resembling those of Loibersdorf.

To the north of these coal-fields and further along the whole border of the Carpathians I know at present of no other certain indication of the presence of the first stage.

Thus it appears that in this first phase of transgression the Mediterranean extended up to the southern edges of the great horsts of western Europe, and that one of its arms, the breadth of which we cannot now even approximately determine, embraced the whole region now occupied by the chief range of the Alps. Against the Swiss and Bavarian Alps we meet only the outcropping ends of upturned strata; towards the north the border of the Rauhe-Alp and the southern edge of the Bohemian mass appear to have nearly coincided with the old coast-line, but brackish deposits are introduced in the direction of the Rhine valley, and the horizon of the Cerithium limestone of Mainz which lies beneath them must be regarded as the chronological equivalent of the whole, or at least of the lower part of the first Mediterranean stage. It appears, however, not only in the bottom of the Rhine valley, but also as an isolated patch near Darmstadt. Such patches serve to strengthen the supposition that the Tertiary deposits, now visible near Mainz, must once have been far more extensive, and that the great trough fault of the Rhine is more recent than these deposits[2].—

It is not necessary to trace in detail the distribution of the first Mediterranean stage further to the south. For the questions which

[1] Untersuchungen über den Charakter der österreichischen Tertiärablagerungen; Sitzungsber. Akad. Wiss. Wien, 1866, LIV, 1. Abth., pp. 87–152.

[2] On this point cf. R. Lepsius, Das Mainzer Becken, 4to, 1883, p. 113, et passim.

concern us here, suffice it to say that the presence of this stage in many localities in that direction furnishes evidence to show that the extension of the sea in the south of Europe, and in a great part of the existing Mediterranean area, was very considerable. Yet the first stage has not, so far as I am aware, been observed on the inner faulted margin of the Carpathians, neither is it known to exist in the subsided basin of Vienna, between the Flysch zone and the Leitha mountains, nor along the fractured margin of the Alps near Güns and Graz; nor is it to be seen in the sunken areas on the inner side of the Apennines. On the other hand, it occurs in many places within the Hungarian plain; near Korod, in Transylvania, the beds of Loibersdorf are again met with. It is widely distributed in the south of Styria and Carniola, where it is thrown into great folds, which strike from east to west.

The beds of Schio and the greensand of Belluno in the southern Alps belong to the first stage; to it also we must refer the serpentinous sands of Turin and the limestones of Monte Titano on the outer side of the Apennines, as well as the lower beds of the island of Malta.

It is known to occur in Corsica and Sardinia, and also along the Algerian coast. Among the fossils collected by Lenz in Morocco, T. Fuchs has identified *Pecten Beudanti*, a characteristic form of the first stage. The specimen was obtained in the district of the Tertiary salt deposits of Fez[1].

We may now leave the west and turn to a series of observations made in the east which throw an unexpected light on the past history of the Mediterranean.

In the region of the Black sea, the sea of Marmara, and the Aegean, no trace of the first Mediterranean stage has hitherto been found. Rumelia and Anatolia formed then, and even in much later times, as will be shown later, a compact continental mass. The ancient extension of the Mediterranean was felt, however, on the southern and eastern border of this land, and has left its traces in highly fossiliferous patches and fragments which, isolated by recent mountain movements and erosion, are met with resting on older rocks, sometimes at astonishing altitudes. It is not always possible from the published information to distinguish whether a particular patch belongs to the first or second stage, but there is no doubt that both stages are represented in this region.

These patches are first met with in Karia, near the village of Germano, on the southern slope of the chain of the Lida, to the east of the island of Kos; they are continued towards the north-east through a series of localities and still further inland; in the same direction a fragment of richly fossiliferous marine Mediterranean beds is met with on the summit of the Davas

[1] O. Lenz, Beiträge zur Kenntniss der Tertiärbildungen in Nord- und Westafrika; Verhandl. geol. Reichsanst., 1883, p. 229.

Dagh, at a height of over 1,360 meters, resting transgressively on upturned older strata. This deposit was discovered by Tchihatcheff and subsequently described by him [1].

A second group of these patches is known in southern Lycia. Spratt and Forbes have found them in four places; the first lies near Arsa on the left bank of the Xanthus, the second near Saaret in the neighbourhood of Antiphellus, more than 800 meters above the sea, the third near Gendever on the west side of the valley of Kassabar at a height of 900 meters, and the fourth, finally, near Armutli, at the southern extremity of the tableland of Armali, at a height of 2,000 meters [2]. Tchihatcheff has found some traces even much further to the north-east, on the other side of this tableland, near Tshobansa.

In Cilicia Petraea these deposits become continuous; according to Tchihatcheff, they extend along the valley of the Gueuk-su from the sea-coast to beyond Ermenek, they then pass around the chain of Topguedik Dagh, formed of ancient rocks, and attain, near Boyalar, not far from Karaman, a height of 1,318 meters. From Karaman onwards they surround on the south-east the older formations, and extend along the coast between Tarsus and Adana [3].

The Mediterranean deposits of the neighbourhood of Tarsus are distinguished by their wide distribution and their richness in organic remains. Russegger observed them many years ago, and traced them along the upper tributaries of the Saihun, far into the mountains. Fossils were found in especial abundance near the village of Hudh on the east side of the Bulgar Dagh [4].

The Mediterranean beds are not confined even to this extensive region. Tchihatcheff's laborious travels have revealed the presence of isolated fragments far in the interior of the country, and in surprising proximity to the shore of the Pontus.

Far to the north, to the east of Tokat, between Alus and Terzi, on the upper course of the Jeshil-Irmak (here Derekojun-Su), sandstone and yellowish limestone with *Pecten planecostatus* and *Anomia costata* are found. Further to the east, to the south of Enderes, a larger patch of these deposits occurs; *Pecten planecostatus* and *Pecten scabrellus* have been collected here. To the south-east of this place the same beds reappear on the upper course of the Euphrates, but it must be particularly noticed

[1] P. de Tchihatcheff, Asie Mineure, IV^e partie, Géologie, III, 8vo, 1869, pp. 15–20; also Bull. Soc. géol. de Fr., 1854, XI, p. 393.

[2] T. A. B. Spratt and E. Forbes, Travels in Lycia, Milyas, and the Cibyratis, 8vo, 1847, II, pp. 169–175; cf. below, note 1, page 316, on some of the points mentioned.

[3] Tchihatcheff, op. cit., IV, 3, pp. 27–60.

[4] J. Russegger, Reise in Griechenland, Unter-Egypten, im nördl. Syrien und südöstl. Kleinasien, 8vo, 1843, II, pp. 607, 628, et passim; by the same, Geognost. Karte des Taurus, fol., Wien, 1842.

that, in spite of their close proximity to the Black sea, they still remain separated from it by a mighty chain of mountains [1].

We have thus no reason to doubt that the eastern part of Asia Minor has suffered great changes of configuration at a comparatively recent period, and that the Mediterranean once covered a great part of this region. The beds at Hudh, although lying far inland, must be assigned, according to the list of fossils published by F. v. Hauer, to the second stage [2]; the more northerly exposures belong, in my opinion, to the first stage.—

Surprising as these facts are in themselves, their full significance was not perceived until the exhaustive researches of Abich had made clear the leading features in the structure of Armenia, Azerbijan, and the Caucasian isthmus. From these researches we learn that the fossiliferous beds of the first Mediterranean stage, in the southern part of this region also, were broken up and carried to great heights by recent mountain movements; they extend in the region of the Euphrates from the neighbourhood of the pass of Sipinkör, north of Erzinghan, to beyond Mamachutun in the country of Terjan (west of Erzerum). They do not, however, reach the Armenian plateau, north of the Araxes, on which only Oligocene deposits have hitherto been observed, but they are prolonged to the south-east, and attain a considerable development on the islands of Lake Urmia and its shores, where they lie unconformably on Palaeozoic rocks [3].

From this region the Mediterranean marine deposits extend far over the Iranian plateau, and Fuchs, from an examination of Tietze's collections, has been led to recognize the presence of the lower part of the first stage in the Siakuh mountains to the south-east of Teheran [4].

Fuchs expressly points out that the assemblage of Mollusca from the Siakuh mountains still bears the stamp of a Mediterranean Tertiary fauna. Tchihatcheff has shown that not even the most northerly of these deposits stands in any connexion with the shores of the Black Sea; in the same way Tietze points out that neither these beds nor the salt deposits of the southern side, of which we shall speak directly, have been observed on the Caspian slopes of the Alburz [5].—

The Oligocene beds of the horizon of Castel Gomberto are known to

[1] Tchihatcheff, tom. cit., pp. 95, 97, 101, 110.

[2] F. v. Hauer in Haidinger's Berichte über Mittheil. d. Freunde d. Naturwiss. Wien, 1848, IV, pp. 311, 312.

[3] H. Abich, Ueber den Steinsalz u. seine geol. Stellung im russ. Armenien, Mém. Acad. Pétersb., 1857, 6e sér., VII, pp. 61–150, 10 pl., and in particular Geol. Forschungen in den kaukas. Ländern, II, Geol. des armenischen Hochlandes, 4to, 1882, pp. 210–327.

[4] T. Fuchs, Ueber die von Dr. E. Tietze aus Persien mitgebrachten Tertiärversteinerungen, Denkschr. Akad. Wien, 1879, XLI, pp. 99–108, 6 pl., and Sitzungsber., 1880, LXXXI, pp. 97–100, and plate.

[5] E. Tietze, Bemerk. über die Tektonik des Albursgebirges; Jahrb. geol. Reichsanst., 1877, XXVII, p. 414.

occur in the West Indies; they reappear in the south of Europe; and Abich has observed them in Armenia.

In the same way, the first Mediterranean stage extends from the Azores and Madeira to Europe and even to Persia. It penetrates from the Atlantic coast into the gulf of the Garonne between the Central Plateau and the northern foot of the Pyrenees, without, it would appear, reaching the present region of the Mediterranean by this path. On the other hand, it advances up the Andalusian strait between the Betic Cordillera and the Iberian Meseta, and there may also have been a more southerly path of communication by Fez. The sea approached the Central Plateau of France from the south, extended into the region now occupied for the greater part by the Jura mountains, probably continued towards the north, where the subsidence of the Rhine valley now lies, as a brackish-water extension, washed against the foot of the Swabian Alps and the Jurassic limestone of Passau, surrounded the Bohemian mass, and following first the outer slopes of the Mannhart, and then the foot of the Devonian mountains north of Brünn, reached the northern confines of Moravia.

Great changes have taken place since that time; from the gulf of Lyons almost to Salzburg, the deposits of the first stage are folded into the forward moved margin of the Alps, and so stupendous has been the transformation of the mountains that at present we can recognize only a few isolated features of the configuration then existing. We can, nevertheless, perceive that the sea extended eastwards as far as Transylvania, and its deposits are represented in the coastal range of northern Africa, in Italy, Sicily, and Malta; but they are entirely absent in the Balkan peninsula, the Pontus, and the western part of Asia Minor.

On the south side of Asia Minor they appear again, and have been traced northwards in isolated fragments as far as the valley of the Jeshil-Irmak and the upper course of the Euphrates, and thence over Lake Urmia into the Iranian tableland.

To whatever extent our knowledge of this subject may be increased or completed in matters of detail, yet owing to the efforts of the numerous observers already mentioned, one fact at least has been definitely established, namely, that at the period during which our marine fauna for the first time assumed in its main features the character of the existing fauna of the Mediterranean, this sea included the present region of the Alps, and extended to the east far beyond Teheran.

We will now trace the steps by which the Mediterranean passed from this first phase to its present condition.

*The Schlier.* The period we are about to discuss is one of the most remarkable episodes in the past history of the Mediterranean. The first great extension, with its diversified deposits of clays, sands, and calcareous sediments, bearing witness to a complete sorting out of the stratified

material, has passed away, and in its place there exists a sea, wherein is laid down, over extraordinarily wide areas, a uniform bluish-grey mud, often strewn through with little flakes of mica. Subsequent changes have converted this mud into a marly, scarcely plastic 'molasse,' sometimes somewhat shaly, sometimes compact and hard, which is known in Upper Austria as the 'Schlier.' Over the district from Upper Austria to Galicia, great lenticular masses of cleanly-washed loose gravel are intercalated in this 'molasse'; in the Apennines similar intercalations of serpentinous sand occur. True limestones are entirely wanting; on the other hand, the Schlier is often accompanied by iodine-bearing or magnesian springs, beds of gypsum or rock-salt, and, indeed, near Kalusch, at the northern foot of the Carpathians, even by those potash salts which are a product of sea-water in a very advanced stage of concentration.

This horizon is everywhere marked by the same fauna, which possesses a very peculiar character. *Aturia Aturi, Solenomya Doederleini, Axinus angulatus, Pecten denudatus, Spatangus austriacus* are among the most characteristic forms; corals are almost exclusively represented by simple forms; sometimes vast numbers of Pteropod shells are met with.

It is strange that this important horizon of the Tertiary formation, which is distinguished by so many constant characters, should have escaped the notice of the older observers.

In 1852 C. Ehrlich, of Linz, described the Schlier of Ottnang in Upper Austria[1]. In the following year M. Hoernes published a list of the Mollusca of Ottnang, which he considered in all essential respects as identical with those of the 'tegel' [brick-clay] of Baden near Vienna, that is, of the deep-water deposits of the second Mediterranean stage[2]. In the year 1866 I identified the bluish-grey marl containing fish scales, which occurs in the extra-Alpine basin of Vienna, with the Schlier of Ottnang, and I was able to show that the latter is an independent member of the Tertiary formation, deposited upon the first Mediterranean stage, and that the bitter springs of Laa, in Lower Austria and many other places, are to be attributed to it; finally, I ventured to advance the hypothesis that the famous salt deposits of Wieliczka in the north were also to be referred to this horizon[3].

Since then the Schlier has been recognized in many other localities in Austria and Hungary, always distinguished by the same characters. In 1872 T. Fuchs announced the surprising discovery that the Austrian

[1] C. Ehrlich, Geognost. Wanderungen im Gebiete der nord-östl. Alpen, 8vo, Linz, 1852, p. 72; a preliminary list of Foraminifera by Reuss is appended.

[2] M. Hoernes, Verzeichniss der in Ottnang vorkommend. Versteinerungen, Jahrb. geol. Reichsanst., 1853, IV, p. 190; also Reuss, Foraminifera von Ottnang, op. cit., 1864, XIV, Verhandl., p. 20. This group of animals was also treated later by F. Karrer, Ueber die Foraminiferen des Schlier in Niederösterr. u. Mähren, Sitzungsber. Akad. Wiss. Wien, 1867, LV, pp. 331-349.

[3] Untersuch. über den Charakter der österr. Tertiärablag., op. cit., 1866, LIV, p. 127.

Schlier was to be met with in Italy, while not long afterwards he showed that the mighty Molasse mountains which, in bold masses cut through by the Reno, form the outer border of the Apennines above Bologna, contain the same characteristic fossils, such as *Aturia Aturi*, *Solenomya Doederleini*, and *Pecten denudatus*, and occupy the same tectonic position as the Schlier on the outer margin of the Carpathians [1]. Finally, after a visit to the islands of Malta and Gozzo in 1876, Fuchs was able to prove that there, too, argillaceous and marly beds, with *Aturia Aturi*, *Pecten denudatus*, and other characteristic fossils of the Schlier, appear between the first and second Mediterranean stages [2]. Then, after the palaeontological researches of R. Hoernes in the north [3] and of Manzoni in the neighbourhood of Bologna [4] had furnished confirmation of these statements, we were able to affirm that not only on the northern edge of the eastern Alps, but over a region extending from the northern border of the Carpathians to Malta, the Schlier was intercalated between the first and second stages of the Mediterranean as an independent, peculiar, and uniform stratified series, distinguished by very remarkable characters [5].

Its extension, according to existing observations, is as follows:—

The Schlier begins in the most easterly parts of Bavaria. It extends in Upper Austria (where it is covered by the more recent deposits of the plain) from the border of the Alps up to the edge of the Bohemian mass. It also forms the basis of the plain still further to the east, from the southern point of the Bohemian mass to the Alps; it rests, to the east of Krems, directly upon granite spurs, and near Grübern, to the south of Meissau, directly upon the uppermost parts of the first Mediterranean stage.

[1] T. Fuchs, Geol. Studien in den Tertiär.-Bildungen Süditaliens, op. cit., 1872, LXVI, 1. Abth., p. 48; by the same, Die Gliederung der tert. Ablag. am Nordabhange der Apenninen von Ancona bis Bologna, op. cit., 1875, LXXI, 1. Abth., p. 164. Also A. Manzoni, Lo Schlier di Ottnang nell' Alta Austria e lo Schlier delle colline di Bologna; Boll. Com. Geol. d'Ital., 1876, VII, pp. 122-132, and in many other places.

[2] T. Fuchs, Das Alter der Tertiärschichten von Malta, Sitzungsber. Akad. Wiss. Wien, 1874, LXX, 1. Abth., pp. 92-102, and Ueber den sog. 'Badner Tegel' auf Malta, op. cit., 1876, LXXIII, 1. Abth., pp. 67-73.

[3] R. Hoernes, Die Fauna des Schliers von Ottnang; Jahrb. geol. Reichsanst., 1875, XXV, pp. 333-400, pl. x-xv.

[4] A. Manzoni, Gli Echinodermi foss. dello Schlier delle colline di Bologna, Denkschr. Akad. Wiss. Wien, 1878, XXXIX, pp. 149-164, 4 pl., and Echinod. foss. della Molassa Serpentinosa, op. cit., 1880, XLII, pp. 185-190, 3 pl.

[5] I must here lay particular emphasis on its independence. The Schlier has sometimes been regarded as a deep-sea formation of the first stage, a view for which I know of no sufficient grounds; quite recently it has been assigned to the second stage, because it contains a large number of species belonging to this stage. But just as the fauna living at present in the Mediterranean comprises elements of various origin, so also do all the earlier faunas, and the exclusive study of lists of species may easily lead to error. We must consider the physical characters as a whole, and when we succeed in tracing a formation over a great space by means of its constant characters it becomes itself the mark of an independent episode of the past, and must be recorded as such.

Where the latter has been denuded away it rests on primitive rocks; it next extends, frequently covered by patches of the second stage, across the present European watershed, forms the greater part of the beds overlying the coal-fields of Ostrau, and thence proceeds towards Troppau and Prussian Silesia. Indications of various dissociation products of the sea are very numerous; they begin with the iodine springs of Hall in Upper Austria. Where overlying beds are absent and the Schlier is freely exposed over considerable areas it often forms impervious surfaces covered with white efflorescences; these, which only support salt-water plants, are the so-called 'Nassgallen.' The lenticular patches of gravel intercalated in the Schlier overlying the coal-fields of Ostrau prove, when they are first sunk into by borings, to be full of water containing a small quantity of salt or iodine; this is the case, e.g., with the basement beds which supply the iodine baths at Gotschalkowitz. In Silesia beds of gypsum and springs of slightly salt water are found in larger number.

Let us now consider the margin of the mountains.

At the point where the first Mediterranean stage disappears in the west, along the Salzach, the Schlier rests against the border of the Flysch zone, and in those few places where observation is possible it is seen to be folded and turned on end. Maintaining this disposition it is continued to the east. Near Staats, in Lower Austria, it forms an obvious arch between the line of the subsided Flysch zone and a projecting ridge of Jurassic limestone. In the neighbourhood of Seelowitz in Moravia it is so well exposed that Rzehak was able to make an attempt at separating it into several distinct subdivisions [1].

We now cross the previously mentioned coal-field of Ostrau, and as we follow the border of the Flysch zone, finally meet the great salt beds of Wieliczka, the folding of which has been discussed in an earlier passage (p. 216). *Pecten denudatus*, *Solenomya Doederleini*, and with these, it is true, many other marine species, which pass up into the beds of the second Mediterranean stage, accompany the salt. The salt deposits form a zone about 30 kilometers in breadth, which follows the foot of the mountains through the whole of Galicia and the Bukowina; in more than two hundred places the presence of salt is revealed by exposures or springs [2].

The beds of this folded zone are continued into the foreland where they lie flat. The observations of Kontkiewicz have shown that to the north of the Vistula, in the south-eastern parts of the kingdom of Poland, there lies over the Chalk a deposit of grey marl with *Ostrea cochlear*,

[1] A. Rzehak, Ueber die Gliederung u. Verbreitung der älteren mediterran. Stufe bei Gross-Seelowitz; Verh. geol. Reichsanst., 1880, pp. 300-303.

[2] M. Kelb, Die Soolequellen von Galizien; Jahrb. geol. Reichsanst., 1876, XXVI, pp. 135, 169, pl. xiv.

*Pecten cristatus*, and *P. Coheni*, and this is succeeded by gypsum. This gypsiferous series with Pectens must be considered as the equivalent of the Carpathian salt zone [1].

The same succession of strata appears, according to Lomnicki, both near Lemberg and throughout the whole of the central part of eastern Galicia; Hilber's careful investigations show that beneath the gypsum *Pecten denudatus* and *P. Coheni* of the Schlier occur, together with a number of species which ascend to the second stage, and above the gypsum follows the second Mediterranean stage [2].

The salt zone of the Carpathians is continued from the southern boundary of Bukowina through Moldavia [3], and even north of Ploesci, in Wallachia, rock salt occurs in the Schlier resting on the flank of the mountains, here turned towards the south-east [4]. To the west of this the younger beds rest against the southern foot of the Fogaras mountains, and the salt zone has vanished [5].

Thus the zone of marine deposits, distinguished by a variety of evaporation products, extends from the iodine springs of Hall through the whole of Lower Austria and Moravia towards Silesia, and forms a mighty saliferous zone along the whole outer edge of the Carpathians right into Wallachia. In the plains this zone corresponds to the gypsum beds of the south-west of Poland and the adjacent parts of Galicia. Some easily recognized fossils, such as *Pecten denudatus* and *P. Coheni*, which are only known in the Schlier, show the connexion between these flat-lying beds and the folded beds of the sub-Carpathian salt zone. In the Sandomir mountains and to the west of them the northern boundary of these deposits may be recognized for a short distance, in the east the shore

[1] S. Kontkiewicz, Kurzer Bericht üb. die von ihm ausgef. geol. Untersuch. im südwestl. Theile v. Königr. Polen; Verh. geol. Reichsanst., 1881, pp. 66-69. The gypsum appears directly over the Pecten bed in a layer which is composed of gigantic crystals, sometimes 2 meters in height, standing side by side in a vertical position. I extremely regret that the second part of J. Niedzwiedzki's admirable monograph on Wieliczka only reached me when these pages were in the press; the results of his careful investigations correspond in all essential points with what I have said here: J. Niedzwiedzki, Beitr. z. Kenntniss der Salzformation von Wieliczka u. Bochnia, 2 parts, 8vo, Lemberg, 1883-1884.

[2] M. Lomnicki, Einiges üb. die Gypsformation in Ostgalizien, Verh. geol. Reichsanst., 1880, pp. 272-275; the fauna in Hilber, Geol. Studien in dem ostgalitz. Miocän-Geb., Jahrb. geol. Reichsanst., 1882, XXXII, pp. 292-297.

[3] V. G. Cobalcescu, Ueb. einige Tertiärbild. in der Moldau; Verh. geol. Reichsanst., 1883, pp. 152-157.

[4] C. D. Pilide, Ueb. das neogene Becken nördl. v. Ploesci, Jahrb. geol. Reichsanst., 1877, XXVII, pp. 132, 140; Paul, Verh. geol. Reichsanst., 1881, pp. 93-95. On the folding of these deposits see Coblacescu, op. cit., 1882, p. 230.

[5] The occurrence of Schlier in the small Tertiary patch of Bahna, above the Iron Gates of the Danube, does not appear to me to be as yet completely established; cf. Stephanesco, Note sur le bassin tertiaire de Bahna, Bull. Soc. géol., 1877, 3e sér., V, pp. 387-393, pl. v, and Tournouër's observations on this.

line is not known; there might well have been a shelving coast on the Russian Platform.—

Let us leave the Carpathians and return once more to the west.

Towards the end of the period in which these saliferous deposits were formed, or immediately after it, great tectonic movements took place over the eastern margin of the Alps. It was at about this time, as we have remarked above (p. 135), that the great intra-Alpine depression of Vienna was formed by the subsidence of the orographic block connecting the Alps and Carpathians, and that the passage across the Alpine system was fashioned through which the existing Danube bears so large a proportion of the Alpine waters to the Black Sea. At the same period the two great sunken areas of Landsee and Graz originated, as well as the present eastern border of the Alps, as far as the Bacher mountains in the south of Styria. In all this vast region the Schlier is nowhere known, or at least nowhere with complete certainty. It is the deposits immediately succeeding the Schlier which rest against the marginal fault of this region.

The same is true, according to Hoernes, of the upper part of the basin of the Save [1].

South of the Bacher mountains, on the other hand, a broad zone of east-to-west folds occurs, which advances far eastwards into the plain, and here we meet with both the first Mediterranean stage and the Schlier.

The Schlier has also been deposited in the vast plain of Pannonia. Thus, for instance, K. Hofmann has observed beds with *Aturia Aturi* superposed on the marine deposits of the first stage in the great and remarkable section of Tertiary deposits near Zsibó, where the river Szamos issues from the Transylvanian caldron into Hungary [2]. Within the great caldron, however, a thick zone of salt is to be seen bordering the foot of the surrounding mountains. In hundreds of places the salt reveals its presence in visible outcrops or by salt springs, and traces of it in the middle of the country show that this zone is only the margin of a saliferous horizon,

[1] Some very subordinate and doubtful exposures occur within the depression of Vienna near Gross Russbach; cf. also T. Fuchs, Jahrb. geol. Reichsanst., 1868, XXVIII, p. 283, note; for the distribution in the south see R. Hoernes, Ein Beitr. z. Kenntniss der mioc. Meeresablag. der Steiermark, Mittheil. naturw. Ver. Steierm., 1882, p. 19. In the south of Styria and in Carniola the Schlier is also known as the 'Mergel von Tüffer'; according to Bittner's observations it bears in some localities a strong resemblance to Hilber's Galician 'beds of Baranow.' This confirmation of the views expressed in the present work is the more valuable, since it proceeds from an observer who does not share them: A. Bittner, Die tert. Ablag. von Trifail u. Sagor, Jahrb. geol. Reichsanst., 1884, XXXIV, pp. 457, 491, 548, 588, et passim.

[2] T. Fuchs, Neues Jahrb. f. Min., 1881, Referate, p. 99. Koch and Kuerthy have shown that in the north-west of Transylvania the great dislocations occurred, as in the eastern Alps, between the first and second Mediterranean stage, so that the latter rest unconformably on the sand of Korod of the first stage: Petrogr. u. tekton. Verhältnisse der trachyt. Gesteine des Vlegyásza-Stockes, Siebenb. Mus. Verein, Klausenburg, 1878, p. 385.

which is continued like a basin over the whole floor of the Transylvanian caldron [1].

Strange indeed must have been the configuration of this region at the time of the Schlier. Although the salt zone of Moldavia is folded on the outer slopes of the Carpathians, and the similar deposits of eastern Transylvania reveal a great disturbance—Posepny's saliferous line of Parajd—yet the chain must have already existed, although not in its present form. This is shown by the fact that a part of the eruptive rocks of the Carpathians is older than the Schlier. The chain was washed on both sides by a sea, in which great masses of salt were deposited. Within the mountains on the east and north side of the caldron rose great volcanos, and there are some indications to suggest that a communication existed between the two salt seas in the direction of the sources of the river Aluta and of the Ojtos pass, that is, in the south-eastern part of the caldron [2].—

The Schlier appears in northern Italy in isolated patches above the beds of Schio, which belong to the first Mediterranean stage. In the neighbourhood of Turin, where it dips to the south, it covers the Schio beds of Gasino and the serpentinous sand of Turin; the latter is considered by some observers to belong to the Schlier itself. On the southern border of the Apennines, as far as Acqui and Serravalle, Schlier occurs again; here it rests directly on the Flysch, as in the Carpathians. The Schlier forms at this place the 'Langhian' stage (étage Langhien) of Pareto and C. Mayer; T. Fuchs has confirmed this correlation. *Aturia Aturi*, *Solenomya Doederleini*, and many other forms characteristic of the Schlier are met with here, but gypsum and salt are absent [3].

Then follow the deposits of Bologna already mentioned. Schlier is found also near Ancona, and other patches of it occur along the outer border of the Apennines [4]. In Sicily the Schlier has been described by Cafici; it is very well developed, particularly in the south-eastern part of the island, and here too it contains *Aturia Aturi* and *Solenomya Doederleini*; it is covered by the second Mediterranean stage [5]. Throughout the whole of Italy these

[1] For a brief account of these rich beds see F. v. Hauer and G. Stache, Geol. Siebenbürgens, 8vo, 1863, pp. 102-110, and F. Posepny, Studien aus dem Salinengebiete Siebenb., Jahrb. geol. Reichsanst., 1867, XVII, pp. 475-516, and 1871, XXI, pp. 123-188, and plate; F. Herbich, Das Széklerland, 8vo, Budapest, 1878, pp. 261-266.

[2] Hauer and Stache, tom. cit., p. 290; Posepny, op. cit., 1871, p. 147. I think the older views of Coquand on the age of the salt beds may be neglected.

[3] C. Mayer, Sur la carte géol. de la Ligurie centrale, Bull. Soc. géol. de Fr., 1877, 3e sér., V, p. 288; T. Fuchs, Studien üb. die Gliederung der jüng. Tertiärbildungen Ober-Italiens, Sitzungsb. Akad. Wiss. Wien, 1878, LXXXVII, 1. Abth., pp. 419-480.

[4] Near Camerino, *Brissopsis Ottnangensis* with *Aturia Aturi* occur in the Schlier: Loriol, Descr. des Échin. des environs de Camerino (Toscane), précédée d'une note stratigraphique par M. Canavari, Mém. Soc. phys. hist. nat. Genève, 1882, XXVIII. Seguenza met with *Aturia Aturi* in the 'Langhiano' near Stilo in Calabria.

[5] Ipp. Cafici, La formazione miocenica nel territorio di Licodia-Eubea; Acad. d. Lyncei, 1883, ser. 3, XIV.

deposits are frequently accompanied by beds rich in Pteropods, as for instance in the north of Moravia. That they are continued into Malta and Gozzo between the first and second Mediterranean stages has already been mentioned.

The Schlier thus follows the outer border of the Apennines, as it does that of the Carpathians, and it extends in flat-lying beds over the foreland towards Ancona, as well as towards the south-east of Sicily and Malta. It is therefore the more remarkable that we have so far no certain proof of its occurrence on the western side of the Apennines over the down-thrown areas of the chain, and in this respect we observe a remarkable correspondence with the eastern Alps. But if we leave the region of these down-throws, in the most northern part of which, west of Genoa and near Savona, the third Mediterranean stage rests directly against the fracture, we again meet at Vence, north-east of Nice, the typical Schlier containing *Pecten denudatus* and other characteristic fossils. It was recognized here by Tournouër as the 'Molasse grise' resting on the 'Molasse jaune de Vence,' which Tournouër rightly compares with the beds of Gaudendorf, that is, to a horizon of the first stage. This locality belongs to the western margin of the Alps, and these beds may be regarded as an outlying member of the deposits of the bay of the Rhone [1].

Up to this point we possess trustworthy indications.

We perceive that from eastern Bavaria to Silesia and around the outer side of the Carpathians as far as Wallachia, then over a great part of Hungary to Transylvania, through a part of the southern Alps near Turin, next around the outer margin of the Apennines to Sicily and Malta, and finally in the most south-western end of the Alps near Vence, there exists a peculiar marine deposit, nearly always grey and marly, which is intercalated between the first and second stages, from each of which it is distinguished by special characteristics. Its fauna contains many species in common with the marine beds above and below it, and yet its stamp is so peculiar that there can seldom be any doubt in referring a particular exposure to this horizon. When for instance the smooth *Pecten denudatus* appears with *Aturia Aturi* in bluish-grey marl near Ottnang in Upper Austria, and the same Pecten appears in similar marl in Malta or at Vence, this recalls rather the uniformity of the Jurassic stages than the diversity of Tertiary deposits.

The great salt deposits of Wieliczka and Bochnia, of Parajd, Déesakna, Thorda, of Maris-Ujvár, Vizakna, and so many other places, the medicinal springs of Hall, Luhatschowitz, Darkau, Gotschalkowitz, and elsewhere, which contain iodine and sometimes also bromine, the bitter spas of Laa,

[1] Tournouër, Notes paléont. sur quelques-uns des terr. tert., &c.; Bull. Soc. géol. de Fr., 1877, 3e sér., V, p. 844.

Seelowitz, and elsewhere, all lie in the briny northern part of this sea, but we can trace the contemporary sediments of the same sea as far as the south of France and Malta.

It would also seem probable that the Schlier is present in Lycia, where we have already recognized the first and second Mediterranean stages. Herr Fuchs has had the kindness to inform me that among the specimens collected by F. von Luschan on his journey from Assa-Altü to Kassaba, and in fact from the scarped edge of the plain of Kassaba, he had found some deposits which exhibit the characters of the Schlier. Numerous fossils occur in a hard pale grey argillaceous marl, which is so crowded with Foraminifera that it presents a sandy appearance. 'The nature of the rock, as well as the frequent occurrence of *Aturia Aturi*, point to the Schlier, a supposition with which all the other fossils accord very well, if we except a single large specimen of *Conus extensus* and another of *Fasciolaria Tarbelliana*, which would rather indicate the horizon of Grund or Gainfahrn (second Mediterranean stage) [1].'

This discovery leads us to the still undecided question whether the extensive salt beds of Persia are also of the same age as those of the Carpathians. A Tertiary deposit following on the first Mediterranean stage and containing salt and gypsum runs from the east of Asia Minor and from Armenia through Azerbijan to the south-east, and is continued eastwards through the whole of northern Persia along the edge of the desert; it extends far beyond Khorasan, and, according to some accounts, even advances as far as Herat. It is known also in some parts of the south of Persia, and forms further a continuous belt along the western edge of the chain of the Zagros, which strike to the south-east. This belt extends from Kurdistan down through the whole valley of the Tigris, and includes the salt beds to the west of Shiraz as well as those of the islands Kishm and Ormuz. This is the 'gypsiferous series' of Loftus [2].

[1] Herr T. Fuchs writes as follows: 'Dr. Tietze visited the same neighbourhood some time after Dr. Luschan, and was kind enough to entrust to me for examination the specimens collected. According to the information which he gave me deposits resembling Schlier occur at many places in Lycia, where they fill narrow valleys; they consist of an alternation of marl, sandstone, and conglomerate, rest on Nummulitic limestone, and have shared in the later movements of the mountains; in appearance they sometimes recall the Flysch. The beds which Tietze met with are of a more sandy nature than those found by Luschan, the Aturia are absent, and the fauna recalls rather the horizon of Grund. Only a few light grey specimens of marl, with numerous Pteropods, Corbula, and Limopsis, approach the type of the Schlier.' The fossils collected by Luschan near Seret in Lycia (probably the Saaret of Forbes) correspond, according to Fuchs, to the deposits of Grund or Lapugy (second stage).

[2] Loftus, On the Geology of Portions of the Turko-Persian Frontier and Districts adjoining, Quart. Journ. Geol. Soc., 1855, XI, p. 247 et seq.; W. T. Blanford, Eastern Persia, An Account of the Journeys of the Persian Boundary Commission, 1870–1872, 8vo, Lond., 1876, II, pp. 461–462. The more recent marine deposits of Tertiary age on the coast of Makrán rest unconformably on the edges of the upturned salt beds.

Abich, who long ago maintained the unity of this great salt and gypsum deposit of the middle Tertiary[1], compares it in his description of the Tertiary system of Armenia and Azerbijan to the Gaj stage, i.e. the gypsiferous stage, which appears in the middle Tertiary formation in the south of Sind.

Dr. Wähner informs me that on the way from Kazwin to Hamadan he met with the very fossiliferous Orbitoides limestone, which forms the basis of the first Mediterranean stage, first near Hissar to the north of the Karaghan mountains, then near Kabutarchan to the south of these mountains, and that in both localities, which are about four days' journey distant from one another, the zones consist of folded and upturned strata. Between the two zones lies the salt district, also very much folded.

Tietze, who knows both the Carpathian and the Persian salt beds from personal observation, regards the latter as more recent than the deposits of the first Mediterranean stage on the Siakuh, and as nearly contemporaneous with those of the Carpathians[2].

At the Caspian Gates, to the south-east of Teheran between the Kuh-i-getsch (mountain of gypsum) and the Kuh-i-nemek (mountain of salt), as well as in the neighbourhood of Kuh-i-getsch towards Hassanabad and towards the desert, the same observer, who has added so much to our knowledge of the north of Persia, found loose yellow sand, which overlies the salt and gypsum deposits, contains great oyster shells, and is believed to correspond in age to the Leithakalk, that is, to the second stage.

I consider this observation as quite decisive. As we shall see directly, however, the penetration of the second stage into the Iranian tableland has not as yet been established by further observations.—

*The Schlier, intercalated between the deposits of the first and second Mediterranean stages, thus affords us the spectacle of a great expiring sea.* This sea may be traced by its sediments and organic remains from Vence near Nice to the south-west of the kingdom of Poland, and to Malta and Gozzo, while fairly certain traces are known in Lycia. It includes the Carpathian salt beds, and many indications suggest that those of Armenia and Azerbijan, of the Iranian tableland as far as Khorasan, of the valley of the Tigris and the coast of the Persian Gulf up to the islands of Ormuz and Kishm, are also to be referred here.

*The second Mediterranean stage.* We are now approaching the end of the salt period. In Lower Austria the upper portions of the Schlier, which are thickly strewn through with crystals of gypsum, show the remains of

[1] H. Abich, Das Steinsalz und seine geol. Stellung im russ. Armenien; Mém. Acad. Sc. Pétersb., 1857, 6e sér., VII, pp. 61–150, 10 pl.

[2] E. Tietze, Verh. geol. Reichsanst., 1875, p. 30; also Die Mineral-Reichthümer Persiens, Jahrb. geol. Reichsanst., 1879, XXIX, pp. 572, 573, and in other places.

land plants, particularly of cinnamon trees; then follow peculiar layers of sand containing either the forerunners of a new marine fauna, or a mixture of this fauna with terrestrial mollusca, or else traces of brackish water. Now for the first time appear those brackish-water faunulae, abounding in shells of Cardium, the facies of which is not unfittingly designated the 'Caspian type.'

Further to the west, from the Randa up to Kirchberg on the Iller, on the Hochsträss near Ulm and down towards Dillingen, that is, on the upper course of the Danube and a little beyond it, as far as the canton Schaffhausen, a fresh-water formation has long been known under the name of the 'Kirchberg beds.' Among its fossils *Oncophora socialis, Unio Eseri*, and *Cardium solitarium* are some of the commonest forms. Near Ehingen, according to Sandberger, these beds lie immediately upon the marine Molasse, i. e. the first Mediterranean stage, and they are covered by fresh-water beds containing *Helix sylvana.*

Near the Danube it has not been possible to trace this horizon further down the stream, but it reappears, as has been shown by Rzehak, in the neighbourhood of Brünn. Just at the point where the valley of the Zwittawa, and with it the great fracture, which separates the Sudetes from the Bohemian mass, reaches the plain, there rises an accumulation of sand, containing the mollusca of the Kirchberg beds enumerated above, and accompanied by the first traces of a new marine fauna; it is inserted between the Schlier and the diversified succeeding sediments of the second Mediterranean stage[1].

Meanwhile the new marginal fracture of the eastern Alps extending from Vienna through Styria as far as the Bacher mountains has been formed. It is not, however, the sea which at once takes possession of the newly formed depressions: beds of brown coal are first deposited along the fractures; they contain a rich terrestrial flora and fauna identical with those which are met with in the upper fresh-water Molasse of Switzerland, in the brown coal of Winterthur, and in the fresh-water limestone of Saussans in the south of France. This is the stage which the Austrian geologists term the '*lignites of Pitten.*'

The sea now invades the country on every side. The first beds which it deposits not infrequently contain brackish-water species; Melanopsis occurs in places in great quantities among the marine mollusca. These lower divisions of the second Mediterranean stage, in which *Pyrula cornuta*

[1] A. Rzehak, Beitr. z. Kenntn. der Tertiärform. im ausseralp. Wiener Becken, Verh. naturf. Vereins in Brünn, 1883, XXI; F. Sandberger, Die Kirchberger Schichten in Oesterr., Verh. geol. Reichsanst., 1883, pp. 208-210. Rzehak found pebbles of Schlier with Aturia in the Oncophora sand. Near Schaffhausen the Schlier is covered by true Jura Nagelflue: F. Schalch, Ueb. einige Tertiärbildungen der Umgeb. v. Schaffhausen, Neu. Jahrb. f. Min., 1881, II, pp. 42-76, pl. iv.

and *Cerithium lignitarum*[1] abound, have recently been regarded as forming an independent stage, and have been designated the '*beds of Grund.*' I have spoken of them here along with the other marine deposits of the second stage without wishing thereby to express any definite opinion as to their claims to a separate existence.

We will begin with the Atlantic coast.

The second Mediterranean stage penetrates into the gulf of the Garonne, where, as we have already seen, it is represented by the faluns of Salles and Saubrigues. These are separated from the first stage by a fresh-water series. The sea extends transgressively as far as Touraine, and there forms a wide gulf into which the Mediterranean deposits had not hitherto penetrated.

The same stage appears near Lisbon; *Pereirea Gervaisi*, a very peculiar Gastropod, is met with here. The deposits follow the coast of Portugal, and enter the gulf of the Guadalquivir; they then appear on the Mediterranean coast of Spain near Barcelona, and in many other places.

They are also present in Morocco, on the coast of North Africa, in Sardinia, Corsica, and the Balearic Islands. They enter the gulf of the Rhone, and then as they proceed north pass into littoral beds with *Nassa Michaudi*, but they do not follow the first stage into the region of the Swiss Alps.

The mode of occurrence of these beds in Italy is very remarkable. They appear in the northern part of the sunken areas in the interior of the Apennines, where they are represented by the limestone of Rosignano, while the collapsed regions further to the south are of more recent origin. At the same time they appear in rich development on the outer border of the Apennines, where they are known as the 'Tortonian stage,' and rest there upon the Schlier, as is also the case in Sicily and Malta.

These deposits must have extended far into the region of the existing southern Alps. In the great trough subsidence lying to the south of the Cima d' Asta, a detached vertical block of these beds with lignite, *Cerithium lignitarum*, Panopaea, &c., occurs on Monte Civerone. It is wedged in between masses of Trias limestone.

In the south of Styria not only do these deposits appear close to the marginal fracture of the Alps, but they also extend into the Alps and, full of their characteristic mollusca, enter the valley of Lavant in the Alps of Carinthia. From the fractured border of the Alps they extend far over the Pannonian plain. In the south-western part of this plain the peculiar *Pereirea Gervaisi* of Lisbon is met with again.

This stage is likewise known near Belgrade; there it extends into the valley of the Morava; it also appears within the mountains at Bahna,

[1] *Pyrazus bidentatus* according to Tournouër, Sur le *Cerith. bidentatum*, Grat., et sur le *Cerith. lignitarum*, Eichw.; Crosse, Journ. de Conchyl., Janv. 1874, pp. 1-8.

near the Iron Gates, while the last known trace of the extension of the Mediterranean in this direction crops out at the foot of the blood-soaked hill of Plevna [1].

In the basin of Pannonia the sea advances on the one hand towards Transylvania, and on the other through the gaps which separate the Leitha mountains from the Alps in the south, and from the Carpathians in the north, to enter the recent Alpine depression of Vienna; and at the same time it extends over the débris of the Flysch zone into the extra-Alpine basin.

Near Vienna, as in Hungary, the diversity of the sediments and the richness of their fauna are astonishing. The blue clay of Baden and Voslau with its Pleurotomas, its simple Corals and Pteropods; the sands of Pötzleinsdorf, rich in bivalves; the beds of limestone built up of Lithothamnium, and between them the marls of Gainfahrn and Steinabrunn, with *Ancillaria glandiformis* and *Venericardia Jouanetti*, with their multitudinous species of Conus, Cypraea, Voluta, Strombus, and Cancellaria; the coarse littoral conglomerates with great Clypeasters, Pectens, and oysters; here and there, too, remains of great coral reefs; all these beds are the deposits of the same sea, laid down in different bathymetric zones. This was asserted many years ago, and has now been established by the careful monographs of T. Fuchs and F. Karrer [2].

In the Alpine portion of the basin of Vienna, the second Mediterranean stage appears as a littoral belt, and is overlaid by more recent beds, which occupy the middle of the depression. Outside the Alpine portion the case is different. The marginal belt is there almost entirely confined to some of the Jurassic 'klippen,' and neither on the outer border of the Alpine zone of Flysch, nor on that of the Bohemian mass, do deposits of this age appear. The stage is represented by certain block-like or tabular masses which rise from the plain above the Schlier as witnesses of extensive denudation. The Buchberg near Mailberg is a block of this kind. It is difficult to determine precisely the extension of the sea towards the west; but it is certain that its deposits are not visible as far as the gorge of the Danube at Wachau near Krems, whereas the Schlier, as we saw above, extends beyond the boundary of Bavaria, and the first Mediterranean stage stretches around the Alps into the valley of the Rhone, where from Lyons onwards it is covered by the sediments of the second stage pushing forwards from the south. These are the first traces of the hydrographical separation of the valley of the Danube from western and southern Europe,

[1] F. Foetterle, Die geolog. Verhältnisse der Gegend zwisch. Nikopoli, Plewna u. Jablanitza in Bulgarien; Verhandl. geol. Reichsanst., 1869, p. 191 et seq.

[2] In particular T. Fuchs and F. Karrer, Ueber das Verhältniss des marinen Tegels zum Leithakalke; Jahrb. geol. Reichsanst., 1871, XXI, pp. 67–122.

a separation which from this time becomes more and more marked, and which is still of such great importance at the present day.—

Although, as we have observed above, these beds do not rest against the outer border of the Bohemian mass, where only the Schlier, the first stage, or the naked rock are visible, yet they extend in the form of a deep bay from the neighbourhood of Brünn towards Bohemia. This bay terminates near Wildenschwert, Abtsdorf, and Böhmisch-Trübau; it is about 85 kilometers in length [1].

Between Brünn and Olmütz there are a large number of block-like hills or buttes left by denudation, of which the highest forms a plateau consisting of Lithothamnium limestone and attains a very uniform height of 350–355 meters. At Ruditz, not far from Brünn, these deposits attain a height of 435 meters, and towards the end of the great Bohemian gulf near Altsdorf of 429 meters [2]. As the result of numerous measurements I have come to the conclusion that the ancient strand-line lay about 440–450 meters above the present sea-level.

This stage now crosses the European watershed, always as patches superposed upon the Schlier, and in the neighbourhood of the watershed it attains a height of 310 meters [3].

It extends towards Silesia, and reaches the south-west part of the kingdom of Poland on the other side of the Vistula, where it overlies the gypsum, and there can be no doubt that the sea of this period overflowed the whole depression of Galicia. On the north and east the boundary of the sea is not known to us, but here and there in the south of Russia inconsiderable remnants of its deposits occur, which show that for some time at least it flowed far over the plain.

These remnants are separated by great distances from each other.

The Russian Platform has been repeatedly covered by the sea since the close of the Permian period.

The first submersion resulted in the deposition of a number of stages of the upper and middle Jurassic, which are known as the 'Jurassic of Moscow.'

The second overflowing occurred during the period of the middle Cretaceous. This transgression extended not only over the Russian Platform, but at the same time over extremely large areas in all four quarters of the globe, and its universal distribution is one of the most problematical phenomena in the history of sedimentary formations.

The third overflowing, although it appears in certain places, especially

[1] A. E. Reuss, Die marin. Tertiärschichten Böhmens; Sitzungsber. Akad. Wiss. Wien, 1860, XXXIX, pp. 207–285, 8 plates.

[2] J. Wolf, Verhandl. geol. Reichsanst., 1862, p. 52: Weihon near Seelowitz, 185·05 fathoms, Urbaniberg near Austerlitz 187·72 fathoms, Kopaninberg near Wischau 185 fathoms.

[3] On the Hranitzki Kopec: Wolf, Verhandl. geol. Reichsanst., 1863, p. 20.

near the sea of Aral[1], to be accompanied by Eocene deposits, belongs essentially to the Oligocene period; it is a prolongation of that great transgression of the Oligocene sea which covered the whole of north-eastern Germany. The northern boundary, within which remains of Oligocene beds are known, runs from the shores of the Baltic near Königsberg towards Thorn, then towards Kiew and Elisabethgrad. Oligocene Mollusca with north European characters are to be met with near Achalzik in Imeretia and also on the shores of the sea of Aral. Oligocene deposits stretch far towards the north along the eastern side of the Ural mountains, and extend eastwards over the Siberian plain. Trautschold mentions fossils of this age from the district of Kamyschloff, and Karpinsky has shown that they occur on the western tributaries of the Tobol as far as the Tura below Werchoturie, that is, about lat. 58° N.[2] It is extremely probable that the Oligocene sea of north Europe, the organic remains of which are distinguished in so striking a manner from the contemporary fauna of the sea of the southern Alps, was in this way connected with the Arctic regions.

The fourth of the transgressions known up to the present is that of the second Mediterranean stage. It advanced from the west over Galicia. Till quite lately, the most remote localities in which this stage was known to occur were those near Elisabethgrad in the north of Kherson described by Barbot de Marny. The patches found here contain *Buccinum miocenicum*, *B. costulatum*, *Mitra scrobiculata*, *Turritella turris*, and other characteristic Mollusca[3]. Even further to the east, however, on the northern side of the peninsula of Kertsch, indications of their occurrence were discovered some years ago by Abich, while the investigations of Andrussow in this region have now placed the matter beyond doubt. Near Tschokrak, on the side of the peninsula facing the sea of Azov, a limestone containing a number of Mollusca of the second Mediterranean stage lies above blue clay; this is in turn covered by the Sarmatian beds which will be discussed presently[4].

[1] Abich, Beiträge zur Palaeont. des asiat. Russlands (from the Mém. Ac. Pétersb.), 1858, and elsewhere. Koenen also suspects from these statements that Nummulitic beds occur in the sea of Aral beneath the Oligocene deposits: Bull. Soc. imp. nat. Moscou, 1868, XLI, p. 171.

[2] H. Trautschold, Traces de l'étage tongrien près de Kamyschloff, Bull. de la Soc. Ouralienne, Ekaterinoslaw, 1882, VII, pp. 21–23, and in particular A. P. Karpinsky, Sédiments tert. du versant oriental de l'Oural, tom. cit., pp. 60–72.

[3] N. Barbot de Marny, Geological Description of the Government of Kherson, 8vo, St. Petersb., 1869, p. 150 (in Russian).

[4] H. Abich, Einleitende Grundzüge der Geol. der Halbinseln Kertsch u. Taman, Mém. Ac. Pétersb., 1865, 7e sér., IX, p. 9 et seq.; N. Andrussow, Observations on Geological Investigations in the Neighbourhood of the town of Kertsch (in Russian), Neuruss. naturf. Gesellsch., 1883, XI, and Verhandl. geol. Reichsanst., 1884, pp. 190–194. Herr Abich has had the kindness to send me the specimens collected in localities still more to the east, and since no decisive conclusion could be drawn from their examination, to

There is nothing, however, in the distribution of any of these remarkable Mediterranean remains to suggest a connexion with the present outline of the Pontus; they lie to the north of that fragment of the Caucasian chain which forms the Crimea.

On the coast of the Black sea itself, as well as of the sea of Marmara and the Aegean sea, throughout the middle of the Balkan peninsula, and in the west of Asia Minor the second, like the first, Mediterranean stage is completely unknown. But it appears to the south of this region in Cyprus and Candia, as well as on the coast of Asia Minor. That the fossils of Hudh are to be assigned to this horizon has already been mentioned. Nevertheless some doubt is permissible as to whether the second Mediterranean stage does actually advance so far towards the east as the first stage and the salt deposits of the Schlier.

Many indications, such as the sand containing oysters, which Tietze observed above the salt at the Caspian Gates, seem to suggest that it did, but the decision must be left to further investigations.

While this question remains unsolved, the southern limits of the stage have been determined by some remarkable observations.

The presence of middle Tertiary marine deposits in the Libyan desert was first recognized by Ehrenberg near the oasis of Siuah, while Fraas furnished the first evidence of their existence between Cairo and Suez, and on the Shalûf along the Suez Canal. Since then Zittel and G. Rohlfs have travelled through the Libyan desert, and we now know that these deposits extend from the Cyrenaica to the oasis of Siuah, forming a wide plateau, which rises to a height of 100 meters above the sea and terminates towards the south in a steep scarp. The plateau and its scarp are continued from the oasis of Siuah towards the north-east. The lowest member of the deposits is formed of greenish salt marl with gypsum and alternating beds of sandy Calcaire grossier and green marl, which lie on Nummulitic limestone. The marine Mediterranean beds in the oasis of Siuah are covered by hard fresh-water limestone and fresh-water quartz [1].

In studying the distribution of these strata near Suez, Beyrich's descriptions are of special importance; they are based on the observations of G. Schweinfurth.

The beds appear not only on the northern slopes of the chain between Cairo and Suez near the Wady Gjáffara, where they have been observed by

institute a fresh search, which it is hoped may prove successful. All the Mollusca of the second stage, collected near Tschokrok, are very small.

[1] K. A. Zittel, Beitr. z. Geol. u. Paläont. der libyschen Wüste u. der angrenzenden Gebiete v. Aegypten, 4to, Cassel, 1883, pp. cxxviii–cxxxii. The presence of Miocene deposits in the Cyrenaica has been confirmed by the subsequent finds made by Schweinfurth near Tobruk: loc. cit., p. cxxxi, note.

Fraas, and on the north-eastern slopes of the Jebel Genéf, where they were found by T. Fuchs resting on gypsiferous marl, but they also extend between Jebel Genéf and Jebel Atáka near Suez, on the one hand, and on the other to Jebel Galála, which projects further to the south towards the Red sea[1]. I attach particular importance to this circumstance. These mountains consist of Cretaceous limestone and older Tertiary beds, which however are more recent than those in the oasis of Siuah, on which the Mediterranean beds rest conformably. While the earlier discoveries of Fraas and Fuchs revealed the presence of the Mediterranean sediments only on the northern slopes of these mountains, we now find them extending south-westwards from Suez, towards the region of the Red sea, the present fauna of which is so different from that of the Mediterranean. It follows that the Erythraean region must have annexed in this place a portion of the ancient Mediterranean, but we must not omit to mention that, in spite of the otherwise uniformly Mediterranean character of these beds, a single alien of Indo-Pacific type—*Placuna miocenica*, Fuchs—has been met with in the oasis of Siuah. These deposits belong, according to T. Fuchs, to the horizon of Grund, that is, to the lower part of the second stage[2]. This conclusion, which is derived from palaeontological comparisons, would assign the inundation of the north-east of Africa to approximately the same period as that in which the Mediterranean for the first time washed against the eastern fractured margin of the Alps.

The difference between the new outline of the Mediterranean and that which it possessed at the time of the first stage is therefore as follows:—

The communication to the north of the Alps, over the Jura mountains and the pre-Alps of Switzerland and Bavaria, has ceased to exist. A permanent extension in the direction of the Euphrates and Persia cannot be proved from present observations. On the other hand, a new extension has taken place from the Loire towards Touraine, and into the sunken areas on the north of the Apennines and of the eastern Alps, over the Schlier of Galicia, towards the southern portion of the Russian plain and the sea of Azov, and finally over the Cyrenaica towards Suez.

*The Sarmatian deposits.* The second Mediterranean stage is followed near Vienna by a stratified series, which in the poverty and uniformity of its fauna presents a wonderful contrast to the second stage; it extends from the valley of the Danube eastwards far beyond that region within which the second Mediterranean stage is known; spreading over a considerable portion of the south of Russia, it appears on the shores of the sea

[1] E. Beyrich, Ueb. geognostische Beobachtungen G. Schweinfurth's in der Wüste zwischen Cairo und Suês; Sitzungsb. Akad. Wiss. Berlin, 1882, X, pp. 163–182, pl. iv, v.

[2] T. Fuchs, Die geol. Beschaffenheit der Landenge von Suez, Denkschr. Akad. Wiss. Wien, 1877, XXXVIII, pp. 25–42, and Beitr. z. Kenntniss der Miocänfauna Aegypt. u. der libyschen Wüste, in Zittel's Beiträgen, pp. 21–66.

of Marmara, of the Black sea, of the sea of Azov, and the Caspian, and reaches the sea of Aral. All this vast region was at this time covered by a sheet of water, which stretched from the eastern Alps to beyond the Ust-Urt. In its extension it surpassed the longitudinal axis of the existing Mediterranean taken from the Straits of Gibraltar to the Syrian coast.

Barbot de Marny, whose energetic and successful efforts to throw light on the past history of the Pontic and Aralo-Caspian depressions resulted first in the loss of his health and then of his life, assisted me in 1866 with much friendly information, when it was proposed to designate these deposits by the independent name of the *Sarmatian stage.* Even at that time it was recognized that the remains of terrestrial mammals, washed into these beds in some places, belong to the same species as those which are also met with in the littoral deposits of the second Mediterranean stage, and that they are older and altogether different from those which are sometimes contained in the third Mediterranean stage; it would therefore be erroneous to compare them chronologically with the third Mediterranean stage[1].

In the Sarmatian marine fauna we observe not only the complete absence of Pteropods, Balani, Brachiopods, Echinoids, and corals, but of all the more richly ornamented forms of Mollusca, and in particular the absence of any indications which would lead us to assume a warm climate. Even in 1866 it was possible to distinguish species of Mollusca surviving in the Sarmatian deposits as the impoverished remains of the preceding Mediterranean faunas, from those which appear as new species. But the former are limited (according to the emphasis laid on subordinate differences) to twenty or thirty species, among which, however, there is no single species of Conus, Cypraea, Oliva, Tritonium, Strombus, or of those numerous other genera which bear witness to the 'warmer habitat' of the second Mediterranean stage. We only find small species of Murex, Cerithium, Pleurotoma, &c. In addition to these there is a large oyster, which some regard as an independent species, others, however, as identical with the *Ostrea Giengensis* of the Mediterranean beds.

Nor are the fresh species, which make their appearance, of essentially different character. *Buccinum duplicatum, Mactra podolica, Tapes gregaria,* are among those which most frequently occur. A greater variety of new forms is developed among the group of the Trochides.

The lack of variety among the species of this molluscan fauna is compensated by the often astonishing number of individuals, the shells of which crowd the beds in millions.

In 1866 the patches of Mediterranean beds in the south of Russia were still unknown, and Humboldt's theory of a comparatively late communication of the Caspian and the sea of Aral with the Arctic Ocean was

[1] Untersuch. üb. den Charakter der österr. Tertiärablagerungen; Sitzungsb. Akad. Wiss. Wien, 1866, LIV, 1. Abth., pp. 87–152.

uncontested. It was therefore natural that the sudden and extraordinary reduction of the Mediterranean fauna, especially the disappearance of all indications of a warm sea and the appearance of new forms, should be considered as coincident with the extension of the sea to the east and the re-establishment of communication with northern waters. Since then our knowledge has increased in every direction, and experienced investigators, such as F. Schmidt, have opposed the theory of a communication with the Arctic Ocean during the Sarmatian period[1]. At the same time the advance made in our knowledge of the relations of the Chinese Han-hai to the depression of Turkestan has brought this question into connexion with a number of others which can only be discussed later; as bearing on this subject the following remarks are of importance.

T. Fuchs asserts that the Sarmatian sea was isolated and was somewhat less salt than the ocean; as a proof of this he lays stress on the similarity of the general character of the deposits, especially as regards their fauna, with that of the present Pontus[2].

R. Hoernes attributes the peculiar poverty of the fauna to local and temporary changes in the saltness of the sea[3].

A. Bittner considers the Sarmatian sea merely as a relic of the Mediterranean, and the Sarmatian fauna near Vienna as a minute fraction of the preceding fauna degenerated or modified by isolation and the influence of brackish water[4].

These three theories agree in the supposition that the communication with the open sea was not sufficient to maintain quite normal conditions within this extensive inland sea; and as soon as all communication to the north or east is left out of consideration the whole Sarmatian sea, notwithstanding its great transgression towards the sea of Aral, the lower Danube, and the sea of Marmara, assumes the subordinate position of a mere annex of the Mediterranean. There is, however, no doubt that a number of species, such as *Mactra podolica, Tapes gregaria,* and others of frequent occurrence, are unknown outside the Sarmatian area[5].

Further, according to the descriptions of Orbigny, Sinzow, Barbot de Marny, and others, there appear in the Sarmatian sands of Bess-

[1] F. Schmidt, Briefe an F. v. Richthofen; Zeitschr. deutsch. geol. Ges., 1877, XXIX, pp. 830 and 837.

[2] T. Fuchs, Ueb. die Natur der sarmatischen Stufe und deren Analoga in der Jetztzeit u. in früheren geol. Epochen; Sitzungsb. Akad. Wiss. Wien, 1877, LXXV, pp. 321–339.

[3] R. Hoernes, Sarmat. Ablagerungen in der Umgebung von Gratz; Mitth. naturw. Ver. f. Steierm., 1878, p. 4 et seq.

[4] A. Bittner, Ueb. den Charakter der sarmat. Fauna des Wiener Beckens; Jahrb. geol. Reichsanst., 1883, XXXIII, pp. 131–150.

[5] Many of these species are probably from other districts; some, for instance, have been quoted from the first stage (Swiss Molasse), but a stricter examination of the facts has not confirmed this quotation.

arabia and the Crimea whole series of new forms of the genera Trochus, Phasianella, Turbo, &c., which are never found in Mediterranean waters [1].

This not unimportant portion of the Sarmatian molluscan fauna must, for the present, be regarded as autochthonous, and it affords us an example of an indigenous fauna, in an extensive part of the sea, which has remained attached to the place of its birth.

To this molluscan fauna, which may thus be regarded as consisting partly of an impoverished Mediterranean residue, and partly of an autochthonous group, we must add a number of fishes and a disproportionately diversified series of marine mammals, which belong to the seals, dolphins, and whales [2]. These mammals appear in the Vienna basin, as well as in Bessarabia and the Crimea.

Near Vienna they occur chiefly in the blue clay which forms the lower part of the Sarmatian stage, and they are accompanied by river, marsh, and land tortoises, as well as by terrestrial plants (Daphnogene, Laurus, Cassia, cones of Conifers) [3].

In these deposits many indications reveal the proximity of a river, but

[1] J. Sinzow in Die Schriften d. neuruss. naturf. Gesellsch. in Odessa, 1875, III, and 1877, V; Barbot in Geol. des Gouvernement Kherson, p. 151 et seq.; also Hoernes, Fauna der sarmat. Ablager. v. Kischineff in Bessarab., Jahrb. geol. Reichsanst., 1874, XXIV, pp. 33–45, pl. ii, iii; A. E. Reuss, Tert. Bryozoen v. Kischinew, Sitzungsber. Akad. Wiss. Wien, 1869, LX, I. Abth., pp. 505–512; F. Karrer and J. Sinzow, Ueb. das Auftreten der Foraminif., Genus Nubecularia, im sarmat. Sande v. Kischinew, loc. cit., 1876, LXXIV, 1. Abth., pp. 272–284 and plates.

[2] K. Peters, *Phoca pontica*, Eichw. bei Wien, Sitzungsber. Akad. Wiss. Wien, 1867, LV, 2. Abth., pp. 110–112; J. F. Brandt, Untersuch. über die foss. u. subfoss. Cetaceen Europa's, Mém. Ac. Pétersb., 1873, 7e sér., XX, and supplements, op. cit., 1874, 7e sér., XXI; P. J. van Beneden, Les Pachyacanthus du Musée de Vienne, Bull. Acad. Belg., 1875, 2e sér., XL.

[3] In the richest locality near Vienna, in Nussdorf, a strange circumstance is observed, namely, that two animals, a mammal and a fish, are characterized by hyperostosis, i. e. a peculiar swelling of the bones. The Sirenid, on which Brandt founded the genus Pachyacanthus, exhibits this characteristic in so high a degree over a large part of the vertebral column that the spinal canal is reduced to a narrow fissure; this phenomenon may be observed to a smaller extent in living Sirenidæ, according to van Beneden chiefly in older individuals. In the fish *Caranx carangopsis* the vertebrae are so overgrown that they can only be recognized as such at their concave ends, and the ribs are covered with large bladder-shaped distensions (F. Steindachner, Beitr. z. Kenntn. der foss. Fischfauna Oesterreichs, Sitzungsber. Akad. Wiss. Wien, 1859, XXXVII, pp. 685–694, pl. v–vii). This fish is allied to the *Caranx carangus* of Brazil and the Antilles, which frequently exhibits similar distensions of certain parts of the skeleton. Herr Steindachner, however, informs me that, notwithstanding the simultaneous occurrence of this phenomenon to such an unusual extent in the individuals of two quite different animals, we cannot draw any conclusion as to the abnormal composition of the sea-water, since thickening of this kind is not rare in the case of Sparoides, Sciaenoides, Carangides, Taenoides, and others, especially in the case of large individuals, and this in normal water. It is known in various other groups of animals and even in man. The specimens from Nussdorf have also been described by P. Gervais, De l'hyperostose chez l'homme et chez les animaux, Journ. de Zool., 1875, IV, pp. 282, 455.

the abundance of crystals of gypsum in the clay point to other conditions, which we cannot now discuss; on the other hand, the presence of oyster beds is an indication of normal salinity. In the sandy deposits the polymorphism of certain bivalves points to changeable conditions, but there are also places, as, for example, in Wiesen to the west of Wiener-Neustadt, and in Kishinev in Bessarabia, where a great variety of species occur in pure sand, and without any indication of abnormal conditions such as might furnish an explanation.

While the Mediterranean fauna has evidently continued to exist in other places, and hundreds of species of this fauna have been perpetuated to the present day, all the autochthonous species of the Sarmatian sea have become extinct: they disappeared simultaneously with the sea itself, and from this results the remarkable fact that the Sarmatian fauna is much further removed from the present Mediterranean fauna than that of the first and second Mediterranean stage. To attempt to determine the age of this fauna according to the percentage of existing forms would, as we observed above, lead to false conclusions, and it is an open question whether the Sarmatian fauna contains even a single species of Mollusca which is still extant.

Surprising and so far unexplained is the isolated occurrence, in the Sarmatian deposits of Galicia, of certain Mollusca which are otherwise alien to this fauna, namely, a Haliotis and two species of Lima[1].

The distribution of the Sarmatian deposits is as follows:—

West of Vienna they appear only at a few points outside the Alpine border, and I know of no certain evidence that they cross the present watershed in the north of Moravia, although Kontkiewicz has observed them in the south-west of the kingdom of Poland. Near Vienna they rest as a rule on the slopes of the second Mediterranean stage, as a step at a somewhat lower level, thus forming a new concentric band; sometimes, however, they cover over this stage, as in the hilly country which separates Lower Austria from Hungary, to the south of the Leitha mountains. The highest deposits of this kind present a littoral character, and lie in this neighbourhood as high as 386 meters on the summit of the Marzer Kogelberg.

They are then continued into the Pannonian plain and as far as Transylvania, they extend to the gulf of Gratz, and south of the Bacher mountains take part in the formation of those east-to-west Tertiary folds which we have already mentioned. In this region they appear in the middle of long narrow synclinals. To the west they penetrate into the Alps as far as Stein in Carniola[2]. They appear here and there on the most

[1] V. Hilber, Geol. Studien in den ostgaliz. Miocän-Gebieten; Jahrb. geol. Reichsanst., 1882, XXXII, p. 309 et seq.

[2] V. Hilber, Ueb. das Miocän, insb. üb. das Auftreten sarmatischer Schichten bei Stein in Krain; op. cit., 1881, XXXI, pp. 473–478.

northerly border of the Bosnian heights, surround the Fruska-Gora near Peterwardein, and are present in the Banat.

The remnants of more recent Tertiary formations, which occur in the south of the Banat at unexpected heights, point to the fact that the communication, which once existed between the area of the Mediterranean deposits near Plevna, and that of the Sarmatian deposits of the lower Danube, must have been closed by later orogenetic movements.

The Sarmatian stage is extensively developed in Wallachia and in the north of Bulgaria. It rests against the south side of the Fogaras mountains, and thence extends northwards through Moldavia and Bessarabia into Bukowina and east Galicia. On the lower Danube it forms, according to Toula, the underlying beds of the plain between the foot of the Balkans and the river as far as the Isker[1]; it is then continued, resting near Plevna on the second Mediterranean stage, to beyond Nikopoli, but the plateau between Rustchuk and Varna is formed of upper Cretaceous, according to Hochstetter, who thinks it probable that the Sarmatian deposits are absent from Sistowa to Tschernawoda[2]. But they certainly occur between Raschowa and Kustendje[3]. Although the Balkans here attain their southern limit, yet they are continued along the western margin of the Black sea, near Baldtjik and Warna, where they were long ago described by Spratt.

They then advance into the sea of Marmara, but, as has been shown by Hochstetter, not into the depression of Adrianople; they form the greater part of the peninsula of Gallipoli, present themselves as horizontal beds on both sides of the Dardanelles, rising to a height of 244 meters above the sea, and lie near Constantinople, as well as near Renkiöi not far from the ruins of Hissarlik, on a fresh-water deposit containing *Anodonta Hellespontica, Melanopsis buccinoidea,* with other species, and regarded both by R. Hoernes and Neumayr as an inferior member of the Sarmatian stage[4].

South of Troy the Sarmatian beds are not known, up to the present, further than the promontory which closes the gulf of Adramyti on the north[5], and neither Samothrace, nor Chios, nor the whole west coast of

[1] F. Toula, Die sarmat. Ablag. zwischen Donau u. Timok, Sitzungsber. Akad. Wiss. Wien, 1877, LXXV, 1. Abth., pp. 113–144 and plate; by the same, Grundlinien der Geol. des westl. Balkan, Denkschr. Akad. Wiss. Wien, 1881, XLIV, p. 39.

[2] F. v. Hochstetter, Die geol. Verhältnisse des östl. Theiles der europ. Türkei; Jahrb. geol. Reichsanst., 1870, XX, p. 401.

[3] K. Peters, Grundlin. z. Geogr. u. Geol. der Dobrudscha, II; Denkschr. Akad. Wiss. Wien, 1867, XXVII, pp. 51, 52.

[4] R. Hoernes, Ein Beitrag z. Kenntn. foss. Binnenfaunen, Sitzungsber. Akad. Wiss. Wien, 1876, LXXIV, 1. Abth., pp. 7-34; Frank Calvert and M. Neumayr, Die jungen Ablagerungen am Hellespont, Denkschr. Akad. Wiss. Wien, 1880, XL, p. 360 et seq.

[5] The little map in J. S. Diller, Notes on the geology of the Troad, Quart. Journ. Geol. Soc., 1883, XXXIX, p. 628.

the gulf of Salonica as far down as Euboea, have furnished any certain indication of these deposits. Certain limnic deposits, which L. Burgerstein observed on the peninsula of Cassandra, may perhaps lend support to the supposition that the Sarmatian sea may have extended as far as this point, although possibly it may not have been so salt here as elsewhere [1].—

Let us now return to the Pontus.

On its southern shore no trace of these deposits is known [2]. On the north, on the other hand, the above-mentioned zone of Sarmatian strata extends from the south of Poland and Galicia, through Podolia and Bessarabia, to be continued on the one side towards Wallachia, and on the other towards the east in the direction of the Russian plain. This zone, which rests in the north on the second Mediterranean stage, is distinguished, both at various localities in Galicia and near Kishinev in Bessarabia, by the presence of some genuine marine species, as well as by the great variety of its fauna. To it belongs the long chain of the Miodobores (honey-woods), which rises to a height of over 400 meters, extends from Podkamia, near Brody, to beyond Kaminiec Podolski, and consists of a Sarmatian Polyzoan-reef; *Pleuropora lapidosa* is the species which has chiefly contributed to the formation of this, as well as of a number of other smaller reefs in Podolia [3].

From the zone of Bessarabia, which extends to beyond the lower Dniester, a belt of Sarmatian deposits stretches eastwards through Stepanowka and Wossnesensk towards Nikopoli and Tauria, overlying in the north the Cretaceous and the granite, and overlaid in the south by the younger limestone of the steppes.

The Sarmatian deposits appear in the Crimea and extend without interruption as far as the isthmus of the Caucasus; there they follow the mountains in the north through Stawropol as far as Derbent; in the south they are known in the river district of the Rion and the Kura. They have shared in the great movements of the chain, and, according to Abich's observations, have been carried up on the Schach-Dagh, near the eastern end of the Caucasus, to a height of 2,330 meters [4].

They then follow the Caspian sea towards the south; Tietze has met with them on the northern side of the Albourz, near Beschel, at the

[1] L. Burgerstein, Geol. Untersuch. im südw. Theile der Halbinsel Chalkidike; Denkschr. Akad. Wiss. Wien, 1880, XL, p. 325.

[2] The information furnished by Brauns calls for a fresh investigation of the peninsula of Sinope: Tchihatcheff, Asie Mineure, Géol., III, p. 150.

[3] N. Barbot de Marny, Ueb. die jüngeren Ablagerungen des südl. Russland, Sitzungsber. Akad. Wiss. Wien, 1866, LIII, pp. 339–342; Hilber, Jahrb. geol. Reichsanst., 1882, p. 311, and in other places; L. Teisseyre, Der podolische Hügelzug der Miodoboren als ein sarmat. Bryozoen-Riff, op. cit., 1884, XXXIV, pp. 299–312; E. v. Dunikowski, Geol. Untersuch. in Russ. Podolien, Zeitschr. deutsch. geol. Ges., 1884, pp. 55, 63.

[4] H. Abich, Prodromus einer Geol. der kaukasischen Länder, 4to, 1858, pp. 152 et seq.

entrance to the valley of the Talar[1]. East of the Caucasus they contribute to the formation of the plateau of Ust-Urt. They rise in horizontal beds on the east side of this plateau, far above the surface of the sea of Aral, and once certainly occupied the whole extent of this inland sea, yet they have not been observed further to the east.

The Sarmatian sea was thus a broad sheet of water which extended beyond the existing sea of Aral, and towards the west, in the present valley of the Danube, was divided into smaller basins. The communication with the open sea was probably not complete, but, apart from exceptional conditions near the coast, the water of this inland sea evidently retained the same composition for a considerable length of time. The several basins to the west had the same composition, and must thus have communicated freely with the great inland sea.

The greater part of the Pontus, or at least the whole north, east, and west, the sea of Marmara, and the north of the Aegean were already accessible to these waters, and they could also reach the Caspian region up to the foot of the Albourz. The relations of this sea with the Asiatic basins will, as we have said, be discussed later.

*The Sarmatian region lies completely outside the present Mediterranean*, if we consider the latter in a restricted sense, i. e. to the exclusion of the Aegean and Pontic seas; the place of union with the Mediterranean is not known, and the greatest variety in the fauna, as well as its most purely marine type, is to be found, strange to say, in the Galician-Bessarabian zone.

*The Pontic deposits.* In the autochthonous species of the Sarmatian inland sea we observed the first indication of a new marine fauna. This germ was not destined to develop further. The subsidence of the coast-line from the sea-level of the second Mediterranean stage to that of the Sarmatian was only the precursor of a further depression of far greater extent. We have indeed reached the period of the greatest shrinking of the Mediterranean. In the region of the Black sea the Sarmatian strata are covered by a group of horizontal beds, which were formed in fresh or slightly brackish water, and which are distinguished by numerous and peculiar species of Cardium, and by genera such as Melanopsis, Valenciennesia, and Congeria. To this group belongs the limestone of the steppes of Odessa. This is the older Aralo-Caspian stage of Murchison, which is now more usually known as the *Pontic* or *Pannonian stage.* It stretches eastwards in the direction of the Caspian sea, in particular into the basin of the Manytsch[2], penetrates on

[1] E. Tietze, Bemerk. üb. die Tektonik des Albursgebirges in Persien; Jahrb. geol. Reichsanst., 1877, XXVII, p. 392.

[2] V. v. Möller, Paläont. Beiträge und Erläut. z. Briefe Danilewsky's üb. die Resultate seiner Reise an d. Manytsch; Mél. phys. chim. Ac. Pétersb., 1878, XI, pp. 55-76.

the south-west into the basin of Adrianople and over the west coast of Chalcidice, and extends westwards far into Wallachia, north-westwards as far as Czortkow in Galicia.

Similar and contemporary deposits fill the basin of Pannonia and that of Vienna.

Near Vienna the Pontic deposits begin in several places with a hard basement bed containing *Congeria triangularis*[1]; then follows thick blue clay, with layers of sand. The series closes here with a purely fluviatile formation, the 'Belvedere schotter,' which descends from the Archaean region in the north-west, that is, from Bohemia, and spreads over the plain as a layer of yellow pebbles and sand. These are the deposits of a river which formed a great delta below Krems, now broken up by denudation into hills[2].

The disposition of the Pontic beds in this region is peculiar. In certain places, as, for example, to the west of Lake Neusiedl, they rest in valleys, which are excavated in the second Mediterranean and the Sarmatian stages. Their deposition must therefore have been preceded by the complete abandonment of the land by the sea, and by the erosion of these valleys by running water. In other places they lie horizontally on the Sarmatian stage at heights which are not inconsiderable, sometimes as much as from 300 to 350 meters, as, for instance, in the neighbourhood of Mödling near Vienna[3].

The explanation of this lies in the fact that after the land had been laid dry and sculptured into hill and valley, the waters of the lake rose gradually till they reached the height just mentioned. Then arose, as already said, the great river coming from Bohemia.

The lake communicated with the other lake basins of the Danube, and so with the sea, as is evident from the fact that several marine fishes were able to ascend nearly as far as Vienna[4].

The traces of this extraordinary retreat of the sea, by which the whole

[1] F. Karrer, Ueb. die Verhältn. der Congerien-Sch. z. sarmat. Stufe bei Liesing, Jahrb. geol. Reichsanst., 1868, XVIII, pp. 273-276; T. Fuchs, Ueb. ein neuartiges Vorkommen v. Cong.-Schicht. b. Gumpoldskirchen, op. cit., 1870, XX, pp. 128-130.

[2] This is the 'Belvedere Schotter' of the Viennese geologists. It corresponds to the gravels of Eppelsheim in the basin of Mainz and of Balta in Podolia, as well as to the Dinotherium sands of the Jura mountains.

[3] T. Fuchs, loc. cit.; F. Karrer, Geol. der Franz Josef-Hochquellen-Leitung, Abh. geol. Reichsanst., 1877, p. 250 et seq. The Eichkogel near Mödling is 1,146 feet high, yet its highest peak is composed of fresh-water limestone, which is superposed on the Pontic stage.

[4] J. Heckel, Jahrb. geol. Reichsanst., 1851, II, Verh., p. 157; probably a Brosmius, related to the cod of the present day; T. Fuchs, Ueb. die Fischfauna der Congerien-Schichten, Verhandl. geol. Reichsanst., 1871, p. 227: Beryx ein Clupeoide u. vielleicht ein Scomberoide. The Sarmatian genus Cetotherium ascends into the Pontic deposits of South Russia: Fuchs, op. cit., 1871, p. 303.

valley of the Danube and the entire Pontic region were abandoned to fresh or brackish water, may also be seen in Italy.

Many years ago Capellini recognized the remains of a Pontic Cardium-fauna above the Tortonian deposits, that is, above the second Mediterranean stage, while a number of later observations, particularly the discovery of the same fauna in Sicily by Cafici, have led to the following results [1].

In the north of Tuscany and in the march of Ancona, on both sides of the Apennines, near Reggio, and as far as Sicily, beds with *Ancillaria glandiformis* and *Cardita Jouanetti*, or their equivalents, are overlaid by a deposit of tripoli, which contains innumerable remains of Radiolaria and Diatomacea, as well as a varied fauna of fishes. This fauna, in which Bosniaski has distinguished nearly a hundred species of fishes, consists according to this investigator of a mixture of genera belonging to the high sea (Clupea, Gadus, Caranx, Rhombus), and numerous small fresh-water fishes (Leuciscus). The general character of the fauna is Mediterranean, with a somewhat northern facies [2].

In the tripoli, molluscan genera, such as Syndosmya, Ervilia, Tapes, and Cardium, are met with, which indicate a certain affinity with the Sarmatian fauna, although corresponding Sarmatian species have not been recognized with certainty. Capellini believed that in these deposits he had actually found the representatives of the Sarmatian stage.

Some observers concluded from the nature of the sediments and the abundance of Diatomacea that this extensive deposit of tripoli had been laid down in a greater depth of water than the underlying beds containing *Cardita Jouanetti*; others believed that the abundance of fresh-water fish and the character of the Mollusca pointed to shallow water and the

[1] From the fairly abundant literature on this subject I will only mention — for the neighbourhood of Turin: Fuchs, Studien, &c., Sitzungsber. Akad. Wiss. Wien, 1878, LXXVII, 1. Abth., p. 419; for Leghorn and the west coast, and for Ancona and Sinigaglia, with the corresponding part of the east coast: G. Capellini, La formaz. gessosa di Castellina marit., Mem. Ac. Bologna, 1874, 3a ser., IV; by the same, Gli strati a congerie e le marne compatte mioceniche dei dintorni di Ancona, Mem. Ac. Lincei, 1879, 3a ser., III; also by the same, Gli strati a congerie e la formaz. gessoso-solfifera nella prov. di Pisa e nei dint. di Livorno, op. cit., 1880, 3a ser., V; S. de Bosniaski, Cenni sopra l'ordinam. cronol. e la natura dei strati terz. sup. nei Monti Livornesi, Rendic. Soc. Tosc. Scienz. Nat. Pisa, 6. lugl. 1879, and by the same, La formaz. gessosa e il secondo piano mediterr. in Italia, op. cit., 14. nov. 1880; for the south and for Sicily: G. Seguenza, Le formaz. terz. nella prov. di Reggio, Atti Ac. Lincei, 1880, 3a ser., VI, in particular p. 161 et seq.; I. Cafici, Le formaz. gess. del Vizzinese e del Licodiano, Boll. Com. geol., 1880, pp. 37-54; E. Cortese, Brevi cenni sulla geol. della parte NE. della Sicilia, op. cit., 1882, XIII, pp. 331-334; S. Mottura, Appendice alla mem. s. form. terz. nella zona solfifera della Sicilia, Mem. Com. geol., 1872, II; E. Stöhr, Sulla posiz. geol. del tufo e del tripoli nella zona solfif. d. Sicil., Boll. Com. geol., 1878, IX, p. 498 et seq.

[2] S. de Bosniaski, La formaz. gess., p. 11, et passim; to this horizon belong also the fish fauna of Licata described by Sauvage.

proximity of the shore; however this may be, it is now certain that above the tripoli normal deposits of the second stage with *Cardita Jouanetti*, *Pecten aduncus*, and others again appear. Stöhr and Bosniaski do not therefore share Capellini's view that the Sarmatian stage is represented by the tripoli, but they regard it merely as an intercalation in the second stage, although it extends over the whole of Italy.

The deposition of these highest beds of the second stage, which are superposed on the tripoli, was followed by a general sinking of the strand-line; on both sides of the Apennines lagoons were formed in which gypsum was deposited. This gypsiferous horizon may be traced in the east from Turin, past Ancona to Reggio; it runs likewise in the west from Sazzano past Leghorn and Volterra down through Tuscany, reappears in the west of Calabria, and proceeds from Reggio into Sicily, where it is widely distributed. The sulphur mines of Sicily belong to this horizon, the sulphur having been produced by the reduction of the gypsum deposited in the lagoons. Tufaceous limestone has also been deposited in many places.

These sediments are poor in organic remains; *Lebias crassicauda* occurs in them. It is the gypsiferous horizon and not the lower lying tripoli which is regarded by Bosniaski, and doubtless rightly, as the true equivalent of the Sarmatian stage.

Near Leghorn and at other places white marl of trifling thickness, with Melanopsis, Planorbis, insects, fresh-water fishes and frogs, occurs above this horizon. The period during which this was deposited was, according to the same observer, that of the greatest regression of the sea.

Then follow, as the highest members of this group of strata, sand, marl, and molasse, probably some gypsum also, and with them the Pontic fauna, with Congeria and the peculiar species of Cardium which occur in the limestone of the steppes of South Russia. This horizon is now known both in the north and the south of the peninsula. It forms the upper part of Mayer's 'stage of Messina' (Piano Messiniano of Seguenza); its correspondence with the Pontic deposits is generally recognized.

Bosniaski, in his valuable studies on this subject, points out that traces of the presence of marine fishes (Dentex, Raja) are found in the Pontic deposits, and he concludes from this that the level of the sea must have been higher than during the formation of the immediately preceding fresh-water beds.

We may recall the fact, first, that west of the lake of Neusiedl the deposition of the Pontic beds was preceded by the erosion of valleys, from which we concluded that the land had been laid dry in the interval between the Sarmatian and Pontic periods; and next, that a few marine fishes had ascended from the sea as far as Vienna. We will now leave Italy and turn to the valley of the Rhone.

Here, too, we learn from the researches of Fontannes that the deposition of the Pontic Cardium beds of Bollène was immediately preceded by the erosion of valleys. The deposits of the second Mediterranean stage are channelled out, and the Cardium beds lie in the channels. Thus in the south of France also a remarkable retreat of the strand-line took place before the deposition of the Cardium beds.

We now recognize the Pontic stage as a deposit of fresh, or slightly brackish, water, extending from the Caspian into the valley of the Rhone. With these characters it covers the south of Russia, penetrates up the valley of the Danube to beyond Vienna, overlies the gypsum on both sides of the Apennines and in Sicily, and lies in the ancient line of erosion of the Rhone valley. Neumayr rightly describes it as a well-marked continental epoch, pointing out that its marine equivalents are not yet known, because the coast-line at this period probably stood lower than at present [1].

We perceive, then, that the maximum of regression probably coincides with the interval between the Sarmatian and Pontic periods; this is indicated by the erosion which took place along the Danube and in the Rhone valley, and by the intercalated beds containing fresh-water fish in Tuscany.

At the time of the maximum of regression, when the Mediterranean probably did not extend further eastwards than Sardinia and Corsica, a change took place in the terrestrial population. The preceding fauna with *Mastodon angustidens*, Palaeomeryx, Listriodon, &c., is supplanted by a new one containing *Mastodon longirostris*, Hippotherium, Antilope, and other forms. Whereas a fair number of cases are known in which remains of the preceding terrestrial fauna with *Mastodon angustidens* occur in littoral marine beds, and this is also true of the terrestrial faunas which follow the Pontic period, yet no trace of the terrestrial fauna of the Pontic period itself has ever been found in any marine formation: so far had the coast retreated.

*From the beginning of the third Mediterranean stage to the present day.* At the close of the Pontic phase the sea broadened itself out once more over the land and covered a great part of the region of Pontic deposits with purely marine strata. The fauna of this sea makes a still greater approach to that of the existing Mediterranean than do those of the first and second stages. Simultaneously with the renewed advance of the sea a fresh terrestrial population once again makes its appearance. This is the beginning of the third Mediterranean stage.

Stupendous changes, the main features of which we recognize with

[1] M. Neumayr, Ueb. den geol. Bau der Insel Kos u. üb. die Gliederung der jungtert. Binnenablagerungen des Archipels; Denkschr. Akad. Wiss. Wien, 1879, XL, pp. 255, 279.

increasing clearness as we approach the present day, lie between this period and modern times. Throughout this long interval there is no recurrence of the isolation and evaporation of so great a portion of the sea as took place between the first and second stages, nor of so considerable a regression of the sea as between the second and third stage. The multiplicity of phenomena is, however, now so great that we can only present them in a very condensed form.

We will begin in the west.

The great denudation to which the gulf of the Gironde was subsequently exposed appears to have erased from it all traces of the third Mediterranean stage. They are, however, well known in the gulf of the Guadalquivir, and may easily be distinguished from those of the second stage. They appear in many places in the western Mediterranean, both on the coast-land of North Africa and on the southern borders of the Iberian Meseta and of the Central Plateau of France, and they penetrate, superposed on the Pontic Cardium beds, far into the Rhone valley, within the pre-Pontic erosion valleys.

They border both slopes of the Apennines, form in the north the deposits of Asti and of Siena, which are distinguished by the abundance of their organic remains, and cover a part of Sicily, resting almost everywhere on the Pontic Cardium beds. An exception seems to be afforded by the most northern part of the gulf of Genoa, where they rest directly on the older rocks of the Alps, and where recent subsidence appears to have occurred; and a second exception is met with at the southern point of the peninsula. To these deposits, which are usually known elsewhere as 'lower Pliocene,' Seguenza has here given the name of 'Piano Zancleano' on account of their peculiar development, and his valuable researches show that the Zancleano overlaps all the preceding stages, resting even on the upturned edges of much older strata, and that it ascends on the slopes of the Aspromonte to the considerable height of 1,200 meters [1].

From the shores of the Ionian sea, as at Gerace, for example, we can see the white cubical masses of the thick Zancleano, formed of friable limestone, sand, and Polyzoa-beds, clothing the dark older rocks, like the remains of a torn mantle, and rising with a very gentle inclination up the mountain. But although I have only visited the lower part of this covering, I must confess I find it difficult to regard the Polyzoa beds of Gerace as a deposit formed at a depth of more than 1,000 meters, seeing that they show so striking a resemblance to the 'coralline,' that is, to the Polyzoan zone of the present Aegean sea, which occurs at a depth of only 20–35 fathoms; and yet this must have been the case if the beds of the Zancleano were

[1] G. Seguenza, Le formaz. terz. nella prov. di Reggio (Calabr.); Atti Accad. Linc., 1880, ser. 3a, VI, pp. 169, 175, et passim.

deposited with their present inclination. Some later movement of the mountains must consequently be assumed here [1].

We shall soon meet in the same region with still more recent marine beds also occurring at considerable heights.—

Although the equivalents of the Zancleano are, as we have said, to be seen on both slopes of the Apennines, and although they attain a considerable development, especially on the north-eastern side of the chain, yet they are completely absent in the northern part of the Adriatic sea, and they are replaced in the interior of the limestone mountains of Dalmatia by fresh-water deposits of the same age. Tietze found them, however, near Dulcigno. They may also be seen on the Ionian Isles, where T. Fuchs observed them with the bedding much disturbed. From here they contribute to form a great belt around the Peloponnesus, associated with younger marine beds of which they form the base.

It is not certain whether deposits of this age reach the islands of Cyprus and Crete; they are not known on the east coast of Africa, they are absent in the Cyclades, and do not penetrate into the Aegean or the Pontic region or the valley of the Danube; the last named does not show any marine remains more recent than the Sarmatian stage.

The extension of the sea both to the north-east and to the south-east must consequently have stopped far short of the limits it attained during the second Mediterranean stage. A further proof of this is afforded by the existence in the valley of the Danube, especially in Slavonia, and also in the islands of the Aegean sea, of fresh-water beds which, as Neumayr has shown in his masterly monograph on the island of Cos, are of the same age as the marine deposits of this stage. We will call them, in accordance with Hochstetter's suggestion, the *Levantine group*.

The Levantine beds with their great abundance of Paludinas prove the existence of a series of larger and smaller fresh-water lakes, traces of which have been already recognized in Dalmatia, in Bosnia, in the north of Greece and in Asia Minor, and every year adds to their discovery in fresh localities. They attain a great thickness in the Aegean region, where they rest on white or variegated marls, which perhaps represent a still older fresh-water deposit. On Cos they reach a height of 330 meters, and remnants of the lower beds lie scattered over Imbros, Lemnos, Samos, and other islands. On Euboea they are of great thickness, and in Locris, near the highest summit of the Karya mountains, Bittner met with Tertiary fluviatile conglomerates, which belong to this stage, at a height of

[1] G. v. Rath, Ein Ausflug nach Calabrien, 8vo, 1871, has published a sketch by myself of Monte Jejunio and the mountain of Gerace which shows this arrangement. The conical summit which rises to the left below the highest mass of Jejunio is said to bear a patch of Tertiary sand, but I have not made an ascent of the mountain.

900 meters above the sea[1]. It is even possible that the thick Tertiary conglomerates of the northern Peloponnesus are to be assigned here; they have been traced by Boblaye and Virlet in the Ziria mountains, south of Trikala, up to a height of 1,500 meters, though it would seem with a marked dip[2]. Finally in their typical form as Paludina beds they extend beyond the Cyclades and even as far as Crete.

The abrupt termination of the Levantine fresh-water beds near the sea led Spratt many years ago to the conclusion that the whole of this part of the Mediterranean owed its origin to a subsidence of recent date, and the travels of Neumayr and his fellow workers have completely confirmed this view.—

At the close of the third stage a great transformation again took place; a new marine formation, containing the fourth Mediterranean fauna or the upper Pliocene, appears. The sea again surrounds the Apennines on both sides; near Rome the marine sands of Monte Mario rest on the blue marls of the Vatican, which in many respects recall the Schlier; in Calabria the contemporary sediments lie on the slopes of the Zancleano and, according to Seguenza, fill channels of erosion in it. They cover a great part of Sicily, but do not reach the Dalmatian coast; the belt which they form around the Peloponnesus attains a fairly uniform height of 500 meters. They proceed as far as the Cyclades and lie, as in Cos, on the Levantine Paludina beds. Yet they do not reach either the Aegean region or the coast of Egypt.

From the moment the sea crosses the boundary of the Levantine fresh-water region, the multiplicity of phenomena increases to such an extent that I find myself compelled again to alter the method of treatment, and must be content to give a concise account of some particular phenomena or events, instead of a chronological survey. The points which I propose to discuss briefly are the transitory appearance of Arctic Mollusca in the Mediterranean and the formation of some sunken areas of recent date. The temporary penetration of the Red sea into the existing Mediterranean region, which is to be observed in Lower Egypt, will be discussed in the next chapter.

*Northern immigrants in the Mediterranean.* Through all the phases in the history of the Mediterranean, and particularly during that great shrinkage of its area which preceded the second stage, as well as during the still greater restriction which introduced and accompanied the period of the Pontic fresh-water lakes, the Atlantic Ocean was the region in which the Mediterranean fauna continued to exist, as represented by its most characteristic species, and from which it was continually replenished to

[1] A. Bittner, Der geol. Bau von Attika, Boeotien, Lokris und Parnassis; Denkschr. Akad. Wiss. Wien, 1878, XL, p. 12.

[2] Puillon de Boblaye et T. Virlet, Expéd. scient. de Morée, II, 2, Géol. et Minér., 4to, Paris, 1833, p. 214.

populate afresh the districts re-invaded by the sea. This is the significance of the dominant western character which marks the affinities of the faunas from the first stage up to the present day.

Many years ago, before a separation had been made between the first and the second stage, it could be shown from M. Hoernes' description of the Tertiary Mollusca of Vienna that many very typical forms occur among them which still exist on the coast of Senegambia, and more recent researches on the Cape Verde islands and the west coast of Africa have increased the number of these examples[1]. But in addition to this very important element the several faunas include other groups of different age and origin, which can only be distinguished by a careful analysis.

Such an analysis, remarkable for its thoroughness, has been made by R. Tournouër of the Mollusca of the *second Mediterranean stage*, as it occurs at *Cabrières* in the gulf of the Rhone.

He distinguishes the following groups: (1) A small number of species, which appear to be the descendants of the ancient types which existed in the European seas during Oligocene or even Eocene times. (2) A much larger group of new and important species which distinguish the Mediterranean from the Oligocene fauna, and give to it its particular character; these allied species are at present to be found in the warmer waters of foreign seas. (3) Species of which the near relations are to be found neither in ancient European seas nor in the warmer waters of the present day, but which appear as new types, some to disappear again in later times, some, however, to persist, and these latter, multiplying and undergoing further development, were the ancestral stock of the present Mediterranean fauna[2].

The principle of Tournouër's classification may be briefly described as a separation into ancient autochthones, immigrants, and young autochthones, the last named consisting of sterile and fertile types. The conversion of the original fauna into that now existing might have been brought about by the progressive extinction of the ancient autochthones, by the continual driving out of the immigrants, by the disappearance of the young sterile types, and finally by the multiplication and ultimate preponderance of the young fertile types. This, however, is not the way in which this great process was accomplished.

In the first place it is not a question of the displacement of the second group alone; before the commencement of the Pontic period the whole marine fauna was expelled from a very large part of the sea, the sea itself was

[1] Ueber die Wohnsitze der Brachiopoden, II, Sitzungsber. Akad. Wiss. Wien, 1860, XXXVIII, p. 159; Ueb. die einstige Verbindung N. Afrikas mit S. Europa, Jahrb. geol. Reichsanst., 1863, XIII, pp. 26, 27; also L. Tausch, Die von Prof. C. Doelter auf den Capverden gesammelten Conchylien, Zeitschr. deutsch. malak. Ges., 1884, pp. 181-188, et passim.

[2] R. Tournouër in Fischer et Tournouër, Invert. fossiles du Mont Léberon (Gaudry, Animaux foss. du Mont Léberon, 4to, 1873), pp. 163-170.

restricted within narrow bounds, while the deposits formed in inland lakes were widely extended. The question, then, is which of the types out of the whole of this expelled fauna were able on the renewed advance of the sea to reach the Mediterranean shores and to maintain themselves there.

From Fontannes' analysis of the *third Mediterranean fauna in the gulf of the Rhone* it is clear that the southern forms lagged behind. This fauna includes 315 species disposed among 143 genera. Of these 143 genera two occur at considerable depths in the existing Mediterranean, but are represented by one or two small species only; two genera are extinct; 16 genera are absent from the present Mediterranean and live, many of them in rich development, in the warmer seas of the present day. They thus indicate the degree of relationship in the third stage to the warmer seas of the present day. But these 16 genera are all, with a single exception, represented in this fauna by a very insignificant number of species, just as in the present Mediterranean the single *Conus mediterraneus* represents, as an isolated epigone, the large and numerous species of Conus of the earlier Mediterranean fauna [1].

In passing from the third to the fourth fauna, or the upper Pliocene, we meet with a completely new element, which has been hitherto foreign to the Mediterranean, namely, a series of northern immigrants. At the same time the representatives of warmer seas become still further reduced in number.

The highly fossiliferous deposits of *Monte Pellegrino* and of *Ficarazzi* near *Palermo* have been assigned by some authors to the fourth fauna, while others have considered them as somewhat more recent. Monterosato distinguishes here 504 species of marine Mollusca, of which 411 still live in the Mediterranean, 27 are not at present found in the Mediterranean, but in the Atlantic or North Atlantic Ocean; the remaining 66 species have so far never been met with among living forms. In the second group there occur such species as *Buccinum Groenlandicum, B. undatum, Trichotropis borealis, Panopaea Norvegica, Mya truncata, Cyprina Islandica,* and others which are at present characteristic of cold northern seas [2].

The appearance of these species doubtless stands in causal connexion with those indications of great cold which are to be observed at the conclusion of the Tertiary period over a great portion of the earth's surface, and especially over the whole of the continent of Europe. It is, however, particularly difficult to fully trace this horizon within the marine deposits

[1] F. Fontannes, Bull. Soc. géol. de Fr., 1882, 3e sér., XI, pp. 116, 117.

[2] Marchese T. A. di Monterosato, Nota intorno alla conchologia fossile di Monte Pellegrino e Ficarazzi, 8vo, Palermo, 1872; the northern species lie (p. 17) near Ficarazzi in a particular layer; also by the same, Catalogo delle conchiglie fossili, &c., Boll. Com. geol. d' Ital., 1877, VIII, pp. 28–42.

of the Mediterranean, and it has up to the present not been accomplished, although as early as 1844 Philippi had pointed out the presence of some species from the extreme north in the south of Sicily.

Let us now compare this fauna from the neighbourhood of Palermo with P. Fischer's analysis of the Molluscan fauna of Rhodes, which is also assigned to the fourth fauna, the upper Pliocene. Of 312 species, 246 still continue to live in the Mediterranean, 58 species are extinct, and only 8 species appear to have emigrated. Of the latter, 3 species live at present on the coast of West Africa or the Cape Verde islands, and one in the west and north of Europe, while 4 are northern species [1].

Neumayr sees in the marine deposits of the *island of Cos*, which overlie the Levantine fresh-water beds, a considerable resemblance to those of Rhodes, and thinks they are of the same age. Of 107 species collected on Cos, 80 are also to be found on Rhodes, but the northern immigrants have so far not yet been met with on Cos [2].

The explanation of the facts in the *south of Calabria* is, however, much more difficult. Seguenza here distinguishes a Sicilian stage (Piano Siciliano) from a Saharan stage (Piano Saariano) which rests on the former unconformably; the northern species are said to pass from the lower stage into the older part of the next stage above, the Piano Saariano.

According to the statements of this observer the Saariano inferiore or the older Quaternary, attains a height of 830 meters above the sea-level overlooking Reggio, and comprises 497 species, of which 300 are Molluscs; 9 of these are northern and only 6 or 7 extinct species.

The Saariano superiore rises to a much less height, its coast-line may have reached to about 250 meters, and it rests against the deposits mentioned above; 515 species are known, among which 310 occur in the Saariano inferiore, but the northern forms are absent. On the other hand, among the 309 Mollusca of this division, we find, besides a great preponderance of existing Mediterranean types, 8 species which still live in warmer waters.

If we take all the groups of invertebrate animals into account we find 11 species belonging to warmer seas; 7 of these live at present on the west coast of Africa, about the Canaries and the Cape Verde islands, and 4 in the Red sea or other warmer seas. In addition 10 to 13 extinct species of Mollusca occur in the Saariano superiore, among which, however, are a few recurrent types from the second or third Mediterranean stage.

From these facts we conclude that at the time when the coast-line reached its highest level the northern species still lingered in the Mediterranean, but that as the sea-level sank they disappeared; while, on the other hand, a few representatives of a warmer climate temporarily reappeared.

[1] P. Fischer, Paléont. des terr. tert. de l'île de Rhodes; Mém. Soc. géol. de Fr., 1877, 3e sér., I, pp. 40–44.

[2] Neumayr, Kos, p. 252.

Finally, as the strand continued to approach its present level, the marine fauna was established as it now exists [1].

There are still further indications of this transitory appearance of a small number of warmer types in post-glacial times. To this quite recent period we may with considerable probability assign the marine deposits of *Tarento,* which appear in the neighbourhood of this harbour as a plateau rising not more than twelve to sixteen meters above the sea, and extend on the one hand towards the Apulian plateau, and on the other to the little island of Pelagosa [2].

On this island Kobelt found, among 260 species of marine Mollusca, only 9 to 11 species which are completely extinct or no longer present in the Mediterranean, and he observed no northern forms. The remaining species belong to the existing fauna of the Mediterranean [3].

In not a few places the northern element is represented only by a single species, *Cyprina Islandica,* and in this case all the other groups are present, from which in the course of time the present population of the Mediterranean has been derived. In the shell-bearing beds of *Valle biaja* the lists of Stefani record 253 species of marine Mollusca; 209 of these still live in the Mediterranean, and of these 115 occur as far as the coasts of Great Britain and Norway; they practically constitute the Celtic element of the fauna; 20 species are survivals from older stages now extinct; two species still live in Senegal, one in the Antilles. One, *Cyprina Islandica,* alone represents the northern element [4].

As I propose to discuss later the intermittent regression of the Mediterranean coast-line up to the historic period, these examples may for the present suffice.

They show how far the composition of the present fauna of the Mediterranean is dependent on the past history of this sea. Recent investigators, such as Jeffreys, have shown that the existing deep-water fauna of the Mediterranean corresponds in a most extraordinary manner

[1] Seguenza, Prov. di Reggio, pp. 237, 315, 336, and in particular p. 345 et seq. 'Piano Siciliano' with northern Mollusca is assigned to the Tertiary as 'Pleistocene,' 'Piano Saariano,' which in its lower parts contains the same northern species, to the Quaternary, and the recurrence of the warmer forms falls in the younger Saariano; these attempts at classification show the difficulty of the subject clearly enough. Mantovani gives a somewhat divergent description of the relations of the beds near Reggio: Alcuni osserv. nei terr. terz. dei dintorni di Reggio Cal., Boll. Com. geol. d' Ital., 1878, pp. 443–468.

[2] T. Fuchs, Die Tertiärbildungen von Tarent; Sitzungsber. Akad. Wiss. Wien, 1874, LXX, pp. 193–197.

[3] W. Kobelt, Verzeichniss der von mir bei Tarent gesamm. foss. Conch., Jahrb. deutsch. malak. Ges., 1874, I, pp. 65–77. The homotaxy of these deposits with those of Lentini in Sicily is emphasized by Fuchs and Bittner, Die plioc. Bildungen v. Syrakus u. Lentini, Sitzungsber. Akad. Wiss. Wien, 1875, LXXI.

[4] C. de Stefani, Sedimenti sottomarini dell' epoca postpliocenica in Italia; Boll. Com. geol. d' Ital., 1876, VII, pp. 272–289; also Neumayr, Kos, p. 251.

with that of the British seas. This is the Celtic element, which, having appeared here in great part during the glacial period, still survives in the deeper regions. The higher zones are populated by the Lusitanian and typical Mediterranean element, with here and there a foreign form of great antiquity, such as the West Indian *Tritonium nobile,* found on the east coast of Sicily [1]. Finally, northern relict forms are not entirely absent, as, for example, the strange Norway lobster, *Nephrops Norvegicus,* which according to Lorenz appears, together with a small number of other northern species, only in the deepest parts of the northern and central Quarnero, and does not occur anywhere else in the whole of the Mediterranean. But in the places where it does occur individuals are so abundant that baskets of them are daily brought to market in Venice, Trieste, and Fiume [2].

The general result of the preceding investigation seems to me to be as follows: since the beginning of the third stage many local events have occurred in the Mediterranean (the most important of which will be discussed directly), many oscillations of the coast-line have since then taken place, but the sea was never again so narrowly restricted as it was immediately before the third stage.

This sea, with its labile coast-line, was first colonized by the third fauna, then the immigrants from the north arrived, and finally, as the climate became milder, some warmer elements again made their appearance. The climate and the position of the coast-line approached more and more closely to their present state, and of each of the earlier immigrations some trace at least remains in the present fauna.

It is therefore extremely difficult, in the present state of our knowledge, to establish exact divisions within the long series of deposits which separate us from the beginning of the third fauna, although within this lengthy period many great changes may easily be recognized [3].

In the investigation we are pursuing the appearance of immigrants from the north must be considered as a fact of primary importance. The tectonic modifications of the Mediterranean basin must, notwithstanding all their grandeur, be regarded merely as local accidents. The appearance of northern forms, on the other hand, resulted from general causes quite independently of these local events; and it affords therefore, in spite of much uncertainty as to detail, due to the incomplete state of our observations, a datum of the highest value in the chronology of the tectonic events.

*The last subsidences.* It is a very remarkable fact that the younger

[1] Kobelt, Jahrb. deutsch. malak. Ges., 1874, I, pp. 347-352.

[2] For its habitats, see J. R. Lorenz, Physikalische Verhältnisse und Vertheilung der Organismen im Quarnerischen Golfe, 8vo, 1863, p. 328.

[3] The same results are obtained by P. Fischer, Île de Rhodes, p. 42, and previously by Philippi, Enumeratio Molluscorum Siciliae, 1844, II, p. 271.

terraced marine deposits which we have just discussed are absent in certain parts of the Mediterranean, either wholly or with the exception of the lowest, and consequently youngest, terraces, and their absence is associated with circumstances which prove the recent age of these parts of the sea.

The most important example of an addition to the sea in very recent times is furnished by the *Aegean* and the *Black sea*. In the south of Russia, as we have seen, the Tongrian sea extended from Samland over the whole plain as far as the eastern side of the Urals. Then followed after a long interval the second Mediterranean stage, which we were able to follow from Galicia to Elisabethgrad and towards Kertsch, without however perceiving (a fact not to be overlooked) any direct communication with the present basin of the Mediterranean. The Sarmatian stage next covered the whole region, extending far towards the sea of Aral. Then followed the Pontic stage, with the limestone of the steppes, marking the time of the greatest shrinkage of the Mediterranean. But whereas in the west, in Italy for example, the Pontic stage is succeeded by the third and fourth Mediterranean stages, in the region of the Black sea this is not the case. On the contrary this region remained for a long time excluded from the Mediterranean.

Events shaped themselves in the Aegean region in a peculiar fashion. It was covered neither by the first nor the second Mediterranean stage. The Sarmatian and Pontic stages extend from the north as far as the Troas; the latter also reaches Chalcidice. During the third Mediterranean stage a deep fresh-water lake stood over the site of the Aegean, a part of that Levantine chain of lakes which stretched from Slavonia to Asia Minor. The Mediterranean lay entirely to the south of this area. Up to this time the existing continent of Europe had always been connected with Asia in this region by a broad tract of dry land.

The events which followed next have been clearly explained by Neumayr[1].

First the southern part of this continent subsided, and the fourth Mediterranean stage penetrated as far as Melos, Rhodes, and the eastern part of the island of Cos; it there deposited marine strata on the fresh-water formations of the Levantine series. This is probably the period in which that great zone of fractures was formed, which is indicated by the volcanic line of the Cyclades passing through Nisyros, Santorin, Melos, Poros, Methana, and Aegina, along which earthquakes and volcanic eruptions continue to the present day. It appears to be continued into the gulf of Corinth, and, according to the structural relations observed by

[1] Neumayr, Kos, p. 273 et seq., and Zur Geschichte des östl. Mittelmeerbeckens, Virchow u. Holtzendorff's Samml. gemeinverst. wiss. Vortr., Heft 392, Berlin, 1882.

T. Fuchs on the isthmus, it there presents all the characters of a great trough fault[1].

At length in very recent times the Aegean continent completely subsided; Levantine fresh-water deposits of great thickness and with broken edges indicate the new coast, the Mediterranean spread far and wide over the Pontic basin, and even overflowed the otherwise regular shores of this sea into the sea of Azov.

A new order of things was thus established; where lofty mountains stood there is now a deep sea, in many places thousands of feet deep, dating from quite recent times, in any case post-glacial. It is even possible that these events were witnessed by man. Mediterranean deposits certainly occur in the Dardanelles and near Gallipoli, but they do not rise more than forty feet above the present sea-level; they contain no northern and only one extinct molluscan species, all the rest are existing Mediterranean shells. Near Gallipoli a flint knife was found which is said to have been obtained from these beds[2]. The valley of the Danube, which so long formed a link in the great chain of depressions extending through south Russia and the interior of Asia, is now separated from them by a part of the Mediterranean. To the west of the existing Black sea is open egress to the rivers and their world of life; to the east of it there is no outflow, and life stagnates.

In the great closed region of the east lies, as the true successor of the old Pontic brackish-water lake, the Caspian sea, which has been deprived of its great tributary, the Danube, by the advance of the Mediterranean over the sunken area of the Aegean. The Danubian character of the piscine fauna of the Caspian filled Filippi with astonishment as early as 1865, long before these facts were known, and from an examination of the Caspian fauna he drew the conclusion that, in studying the physical history of this sea, attention should be directed to the Danube, rather than to its nearer neighbour the Black sea[3].

The present surface of the Caspian sea lies, as is well known, 26 meters below that of the Black sea[4]. Deposits of the Caspian, distinguished by

[1] T. Fuchs, Stud. üb. d. jüngeren tert. Bildungen Griechenlands; Denkschr. Akad. Wiss. Wien, 1877, XXXVII, 2. Abth., pp. 1-42.

[2] Calvert and Neumayr, Junge Ablag. am Hellespont, pp. 366 and 368. As early as 1856 Spratt was acquainted not only with the recent Mediterranean marine deposits in the Dardanelles, but also with a similar deposit at Leftero-Khori, in the bay of Salonica, south of Vardar; it is about thirty feet high, evidently very recent, and rests on fresh-water beds: On the Geology of Varna and the neighbouring parts of Bulgaria, Quart. Journ. Geol. Soc., 1856, XIII, pp. 72-83; On the fresh-water deposits of Euboea, tom. cit., pp. 177-184.

[3] F. de Filippi, Note di un viaggio in Persia, 8vo, Milano, 1865, p. 318.

[4] v. Helmersen, Beitr. z. Kenntniss d. geol. u. physikogeogr. Verhältnisse d. aralokasp. Niederung, Bull. Ac. Pétersb., 1879, XXV, pp. 513-549; in particular p. 543 et seq.

existing species of Mollusca, extend as far as the Uil, Lake Elton, and Tzaritzin, and, according to Stuckenberg, even into the region between Stawropol and Simbirsk on the Volga. Möller has shown from Danilewsky's collections that they extend in the basin of the Manytsch as far westwards as the Metschetnoy-Liman, opposite Orlow Simonik, only 140–150 kilometers from the sea of Azov. But in the region of the Manytsch itself Sarmatian, Pontic, and Caspian beds lie horizontally one on the other[1].

From Konschin's account of the Kara-Kum steppe we learn that its western part presents Aralo-Caspian deposits containing recent Mollusca, while the eastern part is of greater age[2].

Generalizing from the results of these later researches, and of the older observations, and in particular the masterly description of the region as a whole published by Helmerson in 1879, we arrive at the following conclusions[3]:—The Caspian consists of a northern shallow moiety and a southern deeper moiety which attains depths of 1,000 meters, and, as Abich has shown, occupies the site of a sunken and perhaps still sinking part of the Caucasian chain which runs across the Caspian. Communication with the sea of Aral in recent times, that is, since the appearance of the existing molluscan fauna, has only existed in the south across the western part of the Kara-Kum, so that at the time of its greatest extension this sea formed a sort of double lake with two clearly separated parts. The separation was brought about by the rise of the tableland of the Ust-Urt, which, together with the Mugodjar mountains, divided the Caspian basin from the sea of Aral.

Around this great median mass the Aralo-Caspian double lake extended in such a manner that its western half covered a part of the lower Volga in the north, and the basin of the Manytsch in the west, as far as the sea of Azov. Its remaining boundary was determined by the slopes of the Caucasus. In addition an arm branched off from the bay of Krasnowodsk, which became broader in the western part of the Kara-Kum, and was bounded on the north by the southern foot of the Ust-Urt. It embraced the whole of the Aral towards the north; but as this lake lies at present 48·5 meters above the Black sea and 71·1 meters above the Caspian, it is clear that after the separation its water became entirely independent of that of the Caspian. But traces of a still greater extension have been observed above its existing margin, as, for instance, near Mali-basch on the

According to Starinow's historical investigations the last separation would fall in the years 1540–1545.

[1] V. v. Möller, loc. cit. (note 2, page 331).

[2] Konschin, Reiseskizzen aus den Steppen Kara-Kum; Iswest., 1883, pp. 315–332.

[3] v. Helmersen, loc. cit., and (Jakowlew) Zur Geol. der aralokasp. Niederung, op. cit., 1883, XXVIII, pp. 364–379. A previous communication with the sea of Azov is indicated by the presence of living Caspian Mollusca in the latter; E. v. Martens, Ueb. vorderasiat. Conchylien, 4to, 1874, p. 79.

Syr-Daria; and in the south Helmersen has obtained evidence of a level which must have been about 20 meters higher.

Having made these observations on the history of the Pontic region, we will turn for a moment to the gulf of Mexico (*vide* Fig. 37). The north of the gulf is surrounded by horizontal Tertiary beds ($t_1$); on the Atlantic coast the formation of marine deposits proceeded undisturbed ($t_2$), but they did not extend into the gulf; there the inland lake deposits of the Grand Gulf series (*gg*) were laid down. Later, it is true, the Atlantic Ocean again entered the gulf and deposited the marine strata of Port Hudson upon the Grand Gulf series, just as in most recent times the Mediterranean has deposited its sediments upon the beds of the ancient inland lake of the Pontus.

Let us now return to the Mediterranean.

An excellent example of the subsidence of a wide area is afforded by the island of *Malta*, which, as we have already observed, consists of deposits of the first Mediterranean stage, the Schlier, and of the second stage.

The bedding is horizontal, but faults are present which, according to Hutton and Leith Adams[1], run as follows: a principal fault, marked by a series of steep cliffs, extends across Malta from the bay of Fomm-er-rih north-east to the bay of Maddalena. The north-west side is thrown down to a considerable depth, according to Hutton about 350 feet near Fomm-er-rih, and 270 feet at the other end. Two other faults, running in the same direction, bound St. Paul's bay, which forms, together with the valley extending inland from it, a sunken trough. The ridge which now succeeds and is continued into the island of Salmunet is a subsidiary horst; this is the ridge referred to in the Acts of the Apostles, xxvii. 41, as a place having the sea on both sides of it whereon the apostle Paul suffered shipwreck. Melleha bay is also a sunken trough, but these troughs only form part of a great trough-subsidence which occupies the whole space between the fault of Fomm-er-rih and a fault on Gozzo. The latter runs north-east from the ravine of Migier-Scini to the Râs el Kala. Another great fracture, the fault of Malak, follows the south coast of Malta; here too the amount of the throw is 350 feet; it increases, owing to the coming in of a second subordinate fault, to 550 feet; at no great distance from the shore the sea is 500 fathoms deep.

In this way the plateau has given way and sunk inwards; the island of Comino and the straits of Frioul lie in the trough; Malta and Gozzo are fragments of horsts. Spratt, who has rendered such eminent service

[1] F. W. Hutton, Sketch of the Physical Geology of the Island of Malta, Geol. Mag., 1866, III, pp. 145-152, pl. viii, ix; A. Leith Adams, Notes of a Naturalist in the Nile Valley and Malta, 8vo, 1870, pp. 75, 141-147, 174; most of these faults are marked in the geological map of Malta, fol. 1854, by the Earl of Ducie.

towards the elucidation of the physical history of the Mediterranean, believed that the confused manner in which the remains of terrestrial animals occur in the fissures and caves adjacent to the fracture of Malak might have been brought about by a seismic flood [1].

The subsidence of the northern part of the *Adriatic sea*, and its connexion with the fractured area of the southern Alps, has already been discussed (p. 268). The varied series of marine Tertiary deposits, which is visible on the eastern slopes of the Apennines, is completely absent from

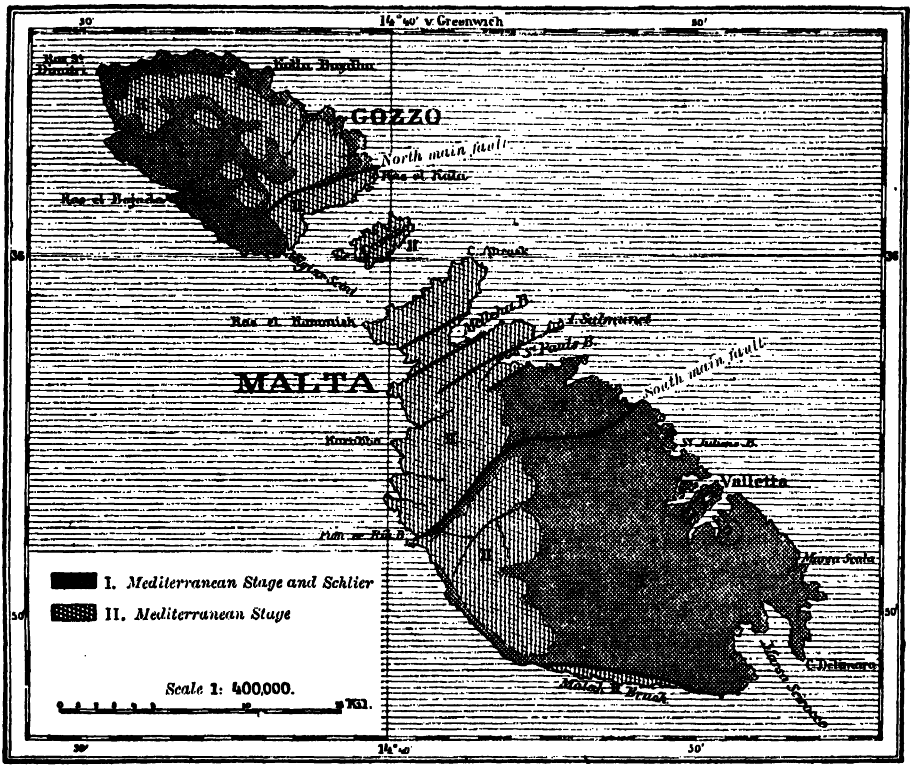



**FIG. 39.** *The trough-subsidence of Malta and Gozzo* (after the Earl of Ducie, Hutton, and Leith-Adams).

the Dalmatian coast as far as Dulcigno. The plateau of marine deposits which extend from Tarento to Pelagosa, where their last trace appears, is, as we have seen, probably of post-glacial age, and the whole marine area situated to the north of the chain of islands, Lagosta-Pelagosa-Tremiti, is still more recent than the post-glacial plateau.

We meet with similar indications in the *Tyrrhenian sea*. A part of the subsidence of the western Apennines, in particular that situated in the

[1] T. A. B. Spratt, On the Bone-caves near Crendi, Zebbug, and Melliha, in the Island of Malta, Quart. Journ. Geol. Soc., 1867, XXIII, p. 296. Dolomieu had previously expressed similar views, but from other reasons.

north of Tuscany, is, judging by the distribution of the second Mediterranean stage, approximately of the same age as the eastern down-break of the Alps, but some of the subsidence is much younger, and movements still persist at the present day (p. 82 et seq.). All the observations hitherto made with reference to the Tyrrhenian sea, and on Sardinia and Corsica, have recently been brought together by Forsyth-Major. On the little island of Pianosa remains of deer have been found, and on Giannutri, which only measures 200 hectares, remains of the stag and a larger Ruminant; a number of similar fossils are known in Elba. Of the sixteen Mammals (exclusive of bats and

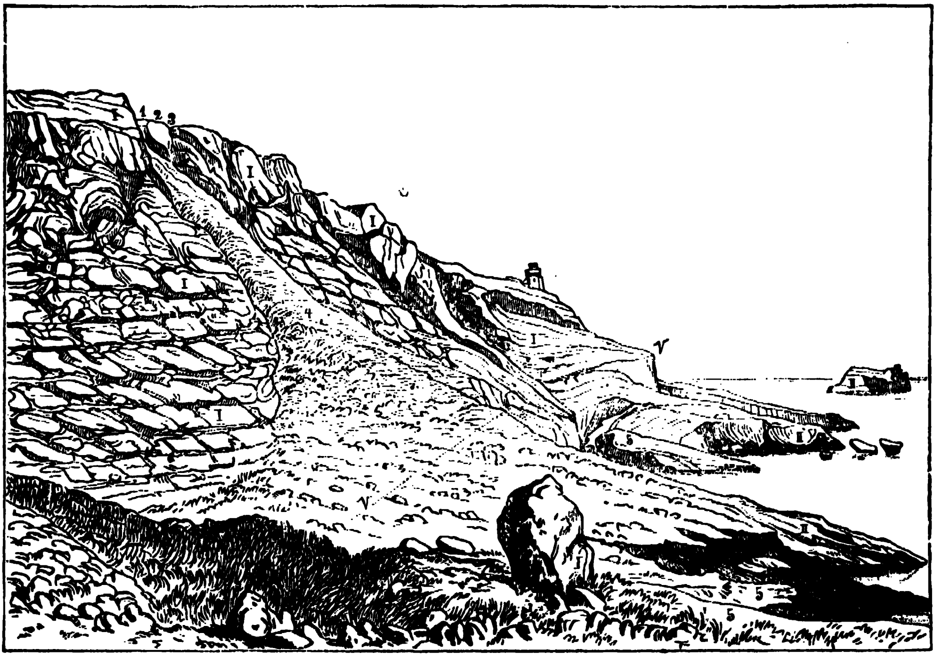


FIG. 40. *View of the fault of Malak on the south coast of the island of Malta* (after Captain Goff in Leith-Adams).

The walls, I, I, are formed by the limestone beds beneath the Schlier (lower limestone); the Schlier is not visible; the second Mediterranean stage, II (upper limestone), lies with dragged-out basset edges at the base; V–V, fault plane; in the background the little island of Filflah; 1, 2, 3, caves and fissures with *Hippopotamus*, *Elephas*, *Myoxus*, &c.; 4, débris out of the cave; 5, breccia with elephant remains.

a few small Insectivores) at present inhabiting Corsica and Sardinia, seven are recorded which do *not* occur on the Italian peninsula, but are all cited as living in Algeria. The country has thus been broken up in quite recent times, but the relationship of the parts cannot at present be completely determined [1].

A large part of the region of the *Syrtis Minor* is formed of a recent

[1] C. J. Forsyth-Major, Die Tyrrhenis, from the magazine Kosmos, 1883, XIII; compare the remark on p. 234.

deposit of sandy loam with beds and loose crystals of gypsum overlying Cretaceous limestone. It contains *Zonites candidissimus* and other existing forms of land-shells, and is continued inland on both declivities of the Shott el-Fedjadj. It is certainly not a marine deposit; nevertheless it dips beneath the sea and forms the group of the Kerkena islands, opposite Sfax [1].

*Formentera*, in contrast to the other Balearic islands, also consists of a recent terrestrial deposit [2].

In *Crete* the remains of the hippopotamus occur in great numbers in recent deposits; not only in Malta, but also in Sicily and in the caverns and clefts of the Rock of Gibraltar, the remains of great terrestrial animals are to be found. It may be observed that *Hyaena spelaea*, which occurs so frequently in caves in England, and is also found in the caves of central Europe, appears near Mentone associated with human remains, and in Gibraltar with African types. This hyena is not identical with the striped hyena (*H. striata*) of North Africa, which appears to have come originally from Asia, but with the spotted hyena (*H. crocuta*) of the south. The jackal still lives, as we said above, on a few of the Dalmatian islands. The porcupine, chameleon, and numerous other forms of animals and plants connect Spain, Sicily, and Italy with the north of Africa.

A theory has repeatedly been put forward that a communication by land existed in quite recent times across the Mediterranean, and that large parts of this sea are of recent origin [3]. But at present it is still very difficult to form a precise opinion on the subject. So much alone is certain, that the fragmentation of the continent was accomplished little by little, and at very different times; and that very great subsidences have affected it since the glacial period.

*Summary*. The preceding facts testify to the following series of changes in the state of the Mediterranean.

The deposits of the middle Cretaceous in Jamaica, and those of the Oligocene period in several of the West Indian islands, present a striking resemblance to the deposits of the same age in the south of Europe. This resemblance persists to a certain extent up to the time when the south of Europe first possessed that marine fauna which furnished the ancestral stock of the existing Mediterranean fauna: in the evolution of the latter

[1] A. Pomel, Géol. de la Petite Syrte et de la région des Chotts Tunisiens, Bull. Soc. géol. de Fr., 1878, 3e sér., VI, pp. 217–224; also Le Sahara, p. 53.

[2] L. M. Vidal y E. Molina, Bosquejo geol. de las islas Ibiza y Formentera; Bol. Com. mápa geol. Esp., 1880, VII, p. 91, sheet B.

[3] Those who have gone furthest in this direction are: A. C. Ramsay, The Geology of Gibraltar and the opposite coast of Africa and the History of the Mediterranean Sea, Proc. Roy. Instit., 1879, VIII, pp. 594–601; and E. Blanchard, Les preuves de la formation récente de la Méditerranée, Comptes rend., 1881, XCIII, pp. 1042–1048; also the observations by A. Milne Edwards, loc. cit., p. 1048; Daubrée, p. 1050; and Hébert, Observ. sur l'état de la Méditerranée à la fin de l'époque tert., tom. cit., pp. 1117–1119.

many characteristic types have been eliminated, and new or foreign elements introduced.

The deposits in which this fauna first appears form the *first Mediterranean stage*. It is not improbable that at this time a large part of the North Atlantic was either dry land, or was interrupted by a series of great islands which have subsequently sunk to profound depths. The waters of the Atlantic Ocean flowed at that time into the gulf of the Gironde, without however reaching by this road the basin of the Mediterranean. Such a communication existed, however, along the line of the Guadalquivir, at the south foot of the Meseta, and there was most probably a still more important communication across Morocco. The sea extended from the south side of the Central Plateau of France through the Rhone district into Switzerland; its deposits appear on the northern border of the Swiss Alps and in some parts of the Jura; it surrounded the southern part of the Bohemian mass, and extended as far as the north of Moravia. It has left traces of its presence in several parts of Hungary, in Transylvania, in the south of Styria, in several parts of the southern Alps, on the outer border of the Apennines, in Corsica, Sardinia, and Malta. Its deposits appear in isolated patches in the extreme south of Asia Minor, and may be traced northwards still further in the east, beyond the sources of the Euphrates; thence they extend past Lake Urmia into the north of Persia.

Above this first and varied group of marine deposits there lies in eastern Europe a broad sheet of bluish-grey clay with *Aturia Aturi* and a number of special forms which constitute an independent horizon; we have given it the name of the *Schlier*. Its most westerly occurrence lies in the neighbourhood of Nice and in Malta. In the east of Bavaria the Schlier runs between the Bohemian mass and the border of the Alps and Carpathians, through Austria, Moravia, and Silesia, and it surrounds the whole outer border of the Carpathians as far as Wallachia. Throughout the whole of this region it is characterized by the presence of gypsum, rock salt, and other products of evaporation. The salt beds of Transylvania also belong to it. The Schlier is likewise known in Hungary; it follows the outer border of the Apennines, and appears with similar characters in the south of Asia Minor. It is not improbable that the extensive Tertiary beds of gypsum and rock salt in the region of the Euphrates and in Persia also belong to the same period as the Schlier.

At the conclusion of this period, which is distinguished by the isolation and concentration by evaporation of large parts of the sea, some of the greatest tectonic changes occurred. At the time when the marine Schlier was involved in the folding of the Alps, the Carpathians, and the Apennines, and contributed to the building up of the outer border of these chains, in other places, as in many parts of Tuscany, Austria, western Hungary, and Styria, great in-sinkings were formed, and in these lie leaf-

bearing lignitiferous beds which are immediately subsequent in age to the Schlier. It is about this time that the Alpine basin of Vienna was broken in, that the Alps were separated from the Carpathians, that the eastern down-break of the Alps with the gulf of Gratz was formed, that the way was prepared for the subsequent discharge of the Danube to the east, and that the Tuscan part of the inner Apennine depression was formed or at least indicated. It is probable that a large part of the inner Carpathian subsidences also belong to this period. In the west the Schlier appears to be represented only by fresh-water beds.

Then the Mediterranean made a fresh advance and the *second Mediterranean stage* was deposited. Not only did the ocean penetrate into the gulf of the Gironde, but it extended transgressively northwards towards Orleans, and once more in all probability it failed to reach the Mediterranean by the gulf of the Gironde. The communication along the Guadalquivir was again in existence. The sea advanced far to the north in the region of the Rhone, but did not reach Switzerland, and there was no communication with the basin of the upper Danube, such as existed at the time of the first Mediterranean stage. On the other hand, this sea has left its traces in the in-sinkings on the inner side of the Apennines and Alps, and just as in the previous stage the sea exceeded its ancient limits in the direction of Orleans, so in this it not only surrounded the Carpathians but spread far over the Russian Platform into the government of Kherson, and even into the neighbourhood of the present sea of Azov. It also reached the southern part of Asia Minor, but it is not certain whether deposits of this period are also present in the interior of the country, in Armenia and Persia.

On the other hand, it is the lower beds of this stage which spread over the Libyan desert into the oasis of Siuah and extend in the neighbourhood of Suez as far as the Red sea, which is at present inhabited by an entirely different fauna.

The second Mediterranean stage is again succeeded in the west by fresh-water beds, while in the east of Europe a new and independent group of strata, the *Sarmatian stage*, makes its appearance.

The Sarmatian must be regarded as a marine stage, although in many places it contains brackish-water intercalations, and although its fauna bears a characteristic impress of uniformity. It fills the depressions of the Danube region from Lower Austria to the Black sea, covers large areas extending from the south of Poland through south Russia to the Caspian and the sea of Aral, and penetrates into the Dardanelles and the northern part of the Aegean sea. The extensive gypsiferous beds on both sides of the Apennines, to which the Sicilian sulphur deposits also belong, are perhaps contemporaneous with the Sarmatian stage.

The Sarmatian is followed by a brackish-water deposit of truly

wonderful extent, characterized by many species of Cardium and by Congeria; this is the *Pontic deposit.* It appears in the valley of the Rhone, where its deposition was preceded by a period of erosion, presents itself on both sides of the Apennines, and is known as far as Sicily. Throughout the region of the Danube plains, from Lower Austria southwards, it rests on the Sarmatian stage, and this is also the case in the south of Russia.

Once more the Mediterranean broadened its bounds; the *third Mediterranean stage* again penetrates into the valley of the Rhone, overlying the Pontic deposits; it occurs in many places within the circumference of the existing Mediterranean, and the inbreak of Genoa appears to belong to this period. But towards the north-east it does not extend beyond Cos, and on the site of the present Aegean sea there was still dry land during this period, with one or more large and deep fresh-water lakes. Nor does this stage penetrate into the interior of Asia Minor.

An extensive oscillation of the coast-line may be recognized along the existing shores of the Mediterranean, by means of the different levels at which the later beds succeed one another, often in distinct terraces. Emigrants from the north, species which live at present in Greenland, made their appearance during this period in the fauna of the Mediterranean; the greater part of these subsequently disappeared, but it is probable that a whole series of the Celtic species, which at present inhabit the deeper and colder regions of the Mediterranean, wandered in about this time.

After this period great subsidences again took place. The Aegean continent, which during the whole of the preceding epoch had extended from Asia Minor and isolated the Pontic region, now subsided, as did also the Pontic region itself up to the northern edge of the western Caucasus, and the Mediterranean thus entered a new and vast region, while in the Caspian basin the former state was maintained. The northern Adriatic also now sank inwards, and in many other places larger or smaller subsidences and attendant faults occurred.

In addition to these events another of a different nature now affected the Mediterranean, namely, a general alteration of the coast-line. This was not a local accident, but, as we shall see later, a very general phenomenon.

The shore deposits abandoned by the sea, which may be seen in many places a few feet above the present sea-level, have doubtless arisen in the same way as the much higher marine terraces, which date from the time of the northern immigrants or even earlier. Many observers have been struck by the contrast between the regularity of these recent terraces on the one hand, and the folds and faults of the mountain chains on the other. The regularity of the 'cordon littoral quaternaire,' that is, of the most recent marine terraces of Cyprus, led Gaudry to distinguish two distinct series of phenomena in the Mediterranean: first, a general sinking of the water-

level; secondly, the formation of dislocations[1]. This distinction between the movements of the water and the movements of the land is of the greatest importance in the study of the changes in the earth's surface.

The series of events we have just passed in review also brings into prominence clearly enough the different parts played by the folding and the sinking movement, or, as we have expressed it above, dislocation in a tangential and dislocation in a vertical direction. In the gulf of the Guadalquivir we have seen to the north the Tertiary shore resting on the southern margin of the Meseta, but towards the south, on the border of the Betic Cordillera, upturned beds and abrupt basset edges. The gulf of the Gironde shows a similar contrast, but the case is not so striking. On the other hand, it is repeated in the Rhone district in the clearest manner, both to the south and to the east of the Bohemian mass.

The *intervening areas,* the depressions which separate the mountain chains from the foreland, *present the appearance of marine areas crumpled up on one side only.* We are not in a position to say how broad that marine area may have been, the deposits of which, under the name of the marine Molasse, may be seen infolded with the outer border of the Alps.

It is, however, evident that those changes which we have attempted to trace in the eventful history of the Mediterranean are not yet at an end. The oscillations of the coast-line still continue. Fresh downbreaks are in preparation. The indications furnished by Calabria in this respect have already been mentioned; R. Hoernes regards the seismic line Görz-Klana-Fiume-Ottocac as a peripheral zone of the fractured area of the Adriatic. Equally remarkable observations have been made in the East. Abich has shown that the eastern Caucasus has sunken in, that its prolongation lies beneath the Caspian sea, and that the great earthquakes of Shemakha-Baskal travel along the fractured margin of a subsidence. The detailed and instructive account of the phenomena which occurred on the lower course of the Kur, in May, 1859, points to the fact that the whole region between Baku, Shemakha, Nucha, Elisabethpol, and Shusha, that is, the entire plain which opens out towards the Caspian sea, behaves in the same way as the sunken area of Calabria and the North Adriatic, i.e. that fresh subsidence is in preparation[2]. This region is adjacent on the west

[1] A. Gaudry, Géol. de l'île de Chypre, Mem. Soc. géol. de Fr., 1859, 2e sér., VII, p. 233.

[2] H. Abich, Geolog. Forschungen, &c., II, p. 427 et seq. 'In order to form a just idea of the extent of these disturbances (the earthquakes in Shemakha) we must bear in mind the fact established by careful investigation, that the central ridge of the Caucasus, at least from Baba-dagh (11,900 feet high) to the sea-coast, represents the northern side of a great fault; this fault destroyed the continuity of an originally flat arch in the direction of its long axis, while the whole of the other side of the fault subsided, in consequence of a general depression of the ground towards the valley of the Kur, and by the formation of other longitudinal faults was resolved into a number of terraces. Geognostic facts which I have observed in the course of wanderings along the coast of the Caspian near

to that zone, stretching southwards from Gotschkai as far as Ararat, which, as far back as historical records extend, i.e. for more than a thousand years, has been visited by the most violent earthquakes. In Armenia we meet with frequent accounts of earthquakes in the lofty volcanic plateau north of Kars, as well as in the neighbourhood of Erzerum. In the same month of May, 1859, at the same time as the shocks wandered far in the east along the lower course of the Kur and the Araxes, this town was suddenly visited by an earthquake which overthrew one-third of the houses and caused the death of hundreds of human beings. From this place a second seismic zone stretches past Lake Van towards Mambedj, Aleppo, and Antioch. In this zone also devastating earthquakes occurred in ancient times, and they have been repeated almost up to the present day (p. 59).

Is the land of the lower Kur, on the south side of the Caucasus, destined to break down in the same way as the eastern prolongation of this chain? Will a new gulf form itself here in the Caspian sea? Or do these repeated earthquakes denote that the whole of eastern Asia Minor will one day collapse, just as the Aegean continent has given way in comparatively recent times, and that as at a recent period the Pontus was united with the Mediterranean, so next the Caspian will be united to it either by way of Antioch or of the coast of Colchis?

We can make no answer to these questions, but we perceive that the old forces are still at work, and we must assume that the changes which they are preparing will be similar to those which have already come to pass.

Lenhoran and Astara, as well as in the Talysch mountains, as far as the plateau of Ardebil, point to the fact that we must consider the area of this sunken region as extending not only over the plain of the valley of the Kur, but also over the southern half of the Caspian sea' (H. Abich, Ueber eine im Caspischen Meere erschienene Insel, Mém. Ac. Pétersb., 7e sér., VI, No. 5, p. 45).

# CHAPTER V

## THE GREAT DESERT PLATEAU

The Sahara and Egypt. South Arabia and Abyssinia. Sinai, Syria, and north Arabia. Suez and the Nile.

*The Sahara and Egypt.* A line drawn across northern Africa from the mouth of the Wady Draa on the Atlantic coast east-north-east to the Mediterranean coast, north of *Syrtis Minor* or the gulf of Gabes, will indicate approximately the boundary between two regions of the earth's crust which differ from one another in structure and composition. The northern region is folded and exhibits a very complete succession of strata; the southern is flat, the succession is interrupted, and a new series of strata does not begin after the Palaeozoic till the Cenomanian transgression.

It is to the broad region in the south that we will now direct our attention. Incomplete in many respects as our knowledge of it may be, yet the simplicity of its structure makes it possible to systematically combine the results of a number of organized investigations which have been carried out by our colleagues in the central and eastern regions of the great desert, together with many isolated observations which have been made in the more distant parts of the south and west by the heroic devotion of explorers such as Duveyrier, Barth, Overweg, Nachtigal, de Bary, Roche, and Oskar Lenz.

A general description of this region was attempted by Pomel as early as 1872, in an excellent work on the Sahara, already mentioned. The whole of western Guinea, as far as the limit of the summer rains between Timbuctu and Saint Louis, would, he says, if sunk to a depth of 200 meters, become an island or peninsula of ancient crystalline rocks or schists. The complicated structure of the Atlas shows its connexion with Europe. The Sahara, as far as the Syrtis (Gulf of Sidra) and beyond, is formed of Palaeozoic and Cretaceous rocks[1].

In 1881 G. Rolland gave a brief survey of the structure of the entire Sahara, as an appendix to an account of his own previous observations, which extended as far as El Goléa, and those of the unfortunate Roche, the distinguished member of Flatter's expedition; he also published the first geological map of the whole central part of the desert from Figig and

[1] Pomel, Le Sahara, pp. 23, 26, et passim.

Gurara in the west to the Black mountains in the east and the mountainous country of Ahaggar in the south [1].

In the preceding year K. Zittel, who accompanied Rohlfs' expedition into the Libyan desert, had published a geological map of the eastern Sahara, extending from the Red sea to the oasis of Siwah, and southwards to the latitude of Edfu. In 1883, however, after the memorable and successful journey of Oskar Lenz through the west as far as Timbuctu, Zittel was able to give a description of the desert as a whole, which was far more complete than those of his predecessors [2].

We will first trace the border of the desert plateau along the folded mountains [Atlas]. Our knowledge of the west is, it is true, still most incomplete, notwithstanding the recent explorations of Fritsch [3] and Lenz [4]. The fact that an independent chain—the Anti-Atlas—composed of ancient rocks, is inserted in the extreme west-south-west, is alone sufficient to show that, in spite of the correspondence in the direction of the mountains, conditions prevail here which are essentially different from those in the east, though of their precise nature we are at present ignorant. In the east of Morocco and to the east of Figig the rectilinear outer border of the mountains consists of upturned Cretaceous beds (p. 226). 'Nothing,' says Rolland, 'can be more striking than the last folds of the Jebel Amour, which rise along a straight line, sometimes almost vertically, in face of the immeasurable Sahara, emerging suddenly from the mantle of recent detritus, which has levelled everything to the south as far as the eye can reach. The Jebel Tizigrarin or Rock of Dogs, on which the town of Laghouat is built, is one of these; an isolated ridge, sharp and jagged, formed of limestone beds, which dip south-east at 45° [5].'

To the west of Biskra a sunken area occurs, somewhat similar to that of Salzburg or Vienna; by this the depression of the Hodna situated in the mountains is connected with the foreland. East of Biskra, however, where on the outer border Nummulitic limestone is visible, in addition

[1] Rolland, Sur le terrain crétacé du Sahara septentr., Compt. rend., 1880, XC, pp. 1576–1578, and Bull. soc. géol. de Fr., 1881, 3e sér., IX, pp. 508–551, pl. xiii–xv; Mission transsaharienne, Géologie et hydrologie, Ann. des Mines, 1880, 7e sér., XVIII, pp. 152–164 and map; further: Roche, Itinéraire de Biskra chez les Touaregs, Compt. rend., 1880, XC, p. 1297; Sur la géologie du Sahara septentr., op. cit., 1880, XCI, pp. 890–893.

[2] K. A. Zittel, Ueber den Bau der libyschen Wüste, Festrede k. bayer. Akad. Wiss., 1880; further: Beiträge zur Geologie und Palaeontologie der libyschen Wüste (Expedition zur Erforschung der libyschen Wüste im Winter 1873-74, ausgeführt von G. Rohlfs), 4to, Cassel, 1883.

[3] C. v. Fritsch, Ueber die geol. Verhältnisse in Marocco; Zeitschr. f. d. ges. Naturw., Halle, 1881, 3. Folge, VI, pp. 201–207.

[4] O. Lenz, Vorläufiger Bericht, in Mittheil. Afrik. Ges., 1880, II, p. 100 et seq.; map in Petermann's Mittheil., 1884; Kurzer Bericht über meine Reise von Tanger nach Timbuktu und Senegambien, Zeitschr. d. Ges. f. Erdk., 1881, XVI, pp. 272–293.

[5] Rolland, Bull. soc. géol. de Fr., 1881, p. 511.

to Cretaceous beds, and where the swerving of the chains in the direction of Cape Bon and towards Sicily becomes apparent, ranges of foot-hills occur, and the simplicity of the boundary is thus lost.

Within these chains of the Atlas the Cenomanian stage rests regularly on the Gault and the lower Cretaceous, and the latter on the Jurassic; older members only reappear further north. If we now enter the region of the Sahara we perceive that from the Cenomanian stage upwards it presents the same petrographical and palaeontological development of the Cretaceous system as the folds of the mountain chains and the 'Hamadas,' i. e. the stone deserts of the foreland. But whereas in the mountains these thick Cretaceous deposits rest on the beds below in normal succession, to the south-west of Figig, a day's journey to the south of Djorf and Torba, they already rest directly on Devonian, and thus at no considerable distance from the outer border of the folded mountains the whole of the lower and middle series of the Mesozoic deposits has disappeared.

In the same way the Nummulitic limestone, which is present in the eastern border of the mountains, disappears in the adjacent desert country, only to recur much further to the east in the Libyan desert; at least no trace of it has as yet been discovered in the region of the Shotts. This might be ascribed to the effect of abrasion, which plays so important a part in the modelling of the Sahara; the Mediterranean beds with *Ostrea longirostris*, however, which occur within the chains in Constantine, also appear on the borders of the Shotts.

If we compare the relations of this eastern part of the folded mountains to its foreland with, say, the relations of the Carpathians to the Russian Platform, we shall find that in North Africa the outer border of the mountains shows steep upturning of the strata, but not overthrusting, and further that an important series of strata, the middle and upper Cretaceous, is continued with unvarying characters into the foreland; it is separated from the great plateaux of the latter only by a broad zone of very recent detritic deposits. The forelands of the two regions present, however, a striking correspondence in the incompleteness and flat bedding of the stratified series and in the transgression which begins with the Cenomanian stage.

The zone of the Shotts, which approaches the Mediterranean near Gabes, belongs entirely to the foreland. Dru has furnished a very instructive description of the Shott el Fejej, and of the Shott el Djerid, connected with the former in the west[1]. The northern border common to the two Shotts is formed by a cliff about 140 kilometers long, which extends west of Gabes as far as the threshold of Kriz, and is continued still further to the west by the spur of Nefta, rising in its highest parts to from 400-500 meters. The central part of this border, which is only 250-300 meters

[1] Dru in Roudaire, Rapport sur la dernière expédition des Chotts, 8vo, Paris, 1881, pp. 45-60.

high, belongs to the Cenomanian stage[1], while towards its extremities the more recent members of the Cretaceous system occur, and the Mediterranean beds with *Ostrea longirostris* appear here and there in fragments which have been thrown down along secondary faults. The southern border is also formed by a cliff with a maximum height of 350 meters, but it is independent of the northern cliff in direction, and is considerably shorter. It also runs from east to west, but is convex towards the south, and ends to the west in a spur which separates the two Shotts. The eastern Shott, Shott el Fejej, presents rocky escarpments to the north and south; the western Shott el Djerid, on the other hand, only to the north, while on the south its shore is flat and undefined.

Dru thinks that the elevation has been accompanied by a mighty subsidence, and he compares the Shotts to a 'buttonhole,' like the well-known *boutonnière* of the Pays de Bray. The fact that relict strand-lines extend to the top of the ridge at the threshold of Gabes, but that in those parts of the Shotts which further to the west sink beneath the level of the sea, no certain traces of a recent marine submersion have been observed, seems to me to indicate the very trifling age of this subsidence.

The disposition of the rocks in the tableland of the Sahara is such that the older appear in the south and east, the younger in the north and particularly towards the delta of the Nile.

The first and oldest zone is formed of granite and gneiss sometimes associated with ancient schist and quartzite. To this zone belong the granite peaks which Lenz met with in El Eglab, on the southern edge of the great sand desert of Igidi in the west. Here too must be assigned the lofty range of Ahaggar, in the interior of which Duveyrier, judging by loose boulders, believes volcanic mountains to occur. The granite and gneiss complex is continued to the north as far as the southern edge of the table mountains of Mudjir and Tazili, and includes the region of the sources of the Wady Ighargar. In the group of the Egere, basalt flows lie in valleys excavated in these ancient rocks.

Barth and von Bary went round the eastern border of the Ahaggar range on their way to Aïr, and the latter has left an exact record of the formations which he encountered; but this journey cost him his life, and once more we add a name to the long list of victims sacrificed to the exploration of the globe[2].

We know that, to the south of Ghat, beyond the table mountains of sandstone and the spurs of the Tazili, granite reappears and forms the

[1] I do not think it necessary to mention the doubtful traces of the Urgo-aptien, because no confirmation has been obtained of the presence of these beds in the promontory.

[2] Tagebuch des verstorbenen Dr. Erwin von Bary, geführt auf seiner Reise von Tripoli nach Ghât und Aïr; Zeitschr. ges. Erdk., 1880, XV, pp. 334–418.

foundation far to the south, nearly as far as Aïr; on this, however, several isolated plateaux of sandstone are superposed, one of which south of Falesles and another much further to the south, near the northern border of Aïr, are specially worthy of mention. These are probably the outposts of the great level Hamadas which extend over a large area towards the oasis of Kawar to the east.

The sandstone and granite are in places accompanied by basalt; amphibolite schists and gneiss also occur. Aïr itself consists of granite; in the neighbourhood of Adshiro volcanic structures are present, for example the

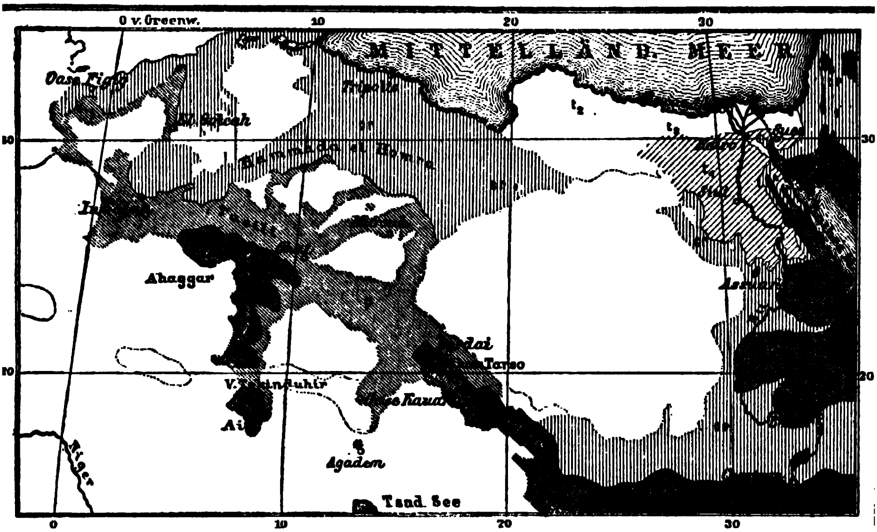



FIG. 41. *Sketch-map showing the distribution of the formations in the desert of Sahara.*
*A*, Archaean; *p*, Palaeozoic; *cr*, middle and upper Cretaceous; $t_1$, Eocene; $t_2$, second Mediterranean stage and more recent deposits. The map is drawn on too small a scale to show the small exposure of Palaeozoic rocks on the peninsula of Sinai; many other details are omitted for the same reason.

volcano Tekinduhir, the lava-fields of which extend into the immediate neighbourhood of Adshiro.

The Tümmo mountains are composed chiefly of sandstone, and the observations of Rohlfs and Nachtigal made on the route from the Tümmos to Lake Chad show clearly that the sandstone plateaux are prolonged towards the south. The steep isolated blocks of rock, which in some localities in Kawar serve as places of refuge in case of hostile attack, consist of the same horizontally stratified sandstone; in Dibbela it is still the prevalent constituent; to the south of this locality, in the Geissinger mountains, Rohlfs mentions the first occurrence of granite, and in Agadem Nachtigal met with stratified limestone[1].

[1] G. Rohlfs, Quer durch Afrika, 8vo, 1874, I, pp. 238-274; G. Nachtigal, Sahărâ und Sûdân, 8vo, 1879, II, pp. 491-554.

It is therefore not impossible that the stratified sediments to the north of Ghat extend southwards into the depression which now contains Lake Chad, the remains of an inland sea, once of much greater extent.

We now enter the mountainous country of Tibesti and meet first the volcano Tarso, 2,500 meters in height; along the edge of its crater in September, 1869, Nachtigal pursued his perilous flight from Bardai. On the south-west side of the volcano granite and sandstone are recorded; the composition of the chain in its continuation to the south-east is unknown; on its southern side in Borgu, north of the oasis Buddu, rises the table mountain Koroka, formed of the blackened sandstone which has here such a wide distribution [1].

The structure of the mountain mass which lies further to the south-east, in Ennedi, is also unknown, and as far as Dar-Fur we have no indication of the geological nature of the country. There, however, those vast plains begin from which Archaean rocks emerge in isolated knolls and masses, forming the whole foundation of the country from Kordofan and Sennar nearly as far as Khartum. Thence these rocks extend to the Red sea and stretch along its shores far to the north, even as far as the gulf of Suez, where, as we shall see later, they are continued through the mountain mass of Sinai to Arabia.

This eastern region, composed chiefly of granite, gneiss, and amphibolite rocks, is very irregularly bounded on the west, where it is overlapped by patches of sedimentary rocks. In many places it advances as far as the Nile, and forms the cataracts; only below Assuan is it confined to a narrower zone running parallel to the sea-shore.

In the south-east, this Archaean region is crowned by the broad volcanic area of Abyssinia and Shoa, which is distinguished by the varied forms of its mountains.

As far as we can at present judge the Archaean foundation of the Sahara is bounded as follows:—

It appears in El Eglab on the southern edge of the great desert Igidi, probably follows this as far as the mountains of Ahaggar, which it includes, and then retreats southwards far to the south of Ghat. Thence to the south as far as Aïr the boundary is very indefinite owing to the superposition of tablelands of sandstone; Archaean rocks do not reappear until we reach the Geissiger mountains north of Agadem, and the slopes of the Tarso (Togar mountains). Thence the northern boundary is unknown for a very long distance; further to the east it runs through the north of Dar-Fur and Kordofan; finally the ancient rocks are deflected far to the north, and thus form a broad basin.

The *second zone* of the Sahara is of Devonian and Carboniferous age.

[1] Nachtigal, tom. cit., p. 111; also p. 109, blackish sandstone of the oasis of Kirdi in Borgu. In the Egei the slopes are terraced down to the plain.

The specimens brought home by Lenz from the desert in the west have enabled Stache to show that the rock underlying the region between the Atlas and the desert of Igidi is formed for long distances by marine beds of Carboniferous age[1]. I have already mentioned the Palaeozoic limestone, which far to the north, near Djorf and Torba, underlies the Cretaceous. On the eastern edge of the sandy desert, near Gurara in the Tidikelt, Palaeozoic rocks crop out; their flat-lying beds form that zone of table mountains on the northern border of the Ahaggars, to which Mudjir, Irauen, Tazili, Egele, Akakus near Ghat, and as a prolongation, Amsak and others belong. In several places Devonian fossils have been met with, but in the region of Murzak there are also traces of Carboniferous beds[2].

The blackened sandstones of Tazili, supposed to be Devonian, appear to be the same as those which we have just traced above as far as the northern boundary of Aïr and even as far as Borgu.

This zone is broad in the west, appears to be narrowest to the south of Timassinim on the north side of the mountains of Ahaggar, and expands again to the north, as is shown by the occurrence of Devonian fossils at the spring of El Hassi. East of Murzuk, however, all traces of this zone are lost, and no evidence of Palaeozoic marine deposits has as yet been furnished by any part of the eastern border, down to the peninsula of Sinai.

The *third zone* is formed of Cretaceous rocks. Although isolated patches of this zone are known in Morocco, yet we shall take it to begin with the great continuous cliff of Cenomanian, which rises to the south of Laghouat, runs through El Golea towards In Salah, there turns sharply to the east, and enveloping the table mountains of Tademaut and Tingert, finally forms the southern border of the great Hamada el-Homra. The whole area lying within the curve described by this great cliff, as far as the Shotts, that is, the whole middle and lower region of the Wady Igharghar, together with the great sandy desert which lies to the west of Ghadames, belongs to this zone. It rises in the direction of Tripoli towards the Mediterranean, where it attains the not inconsiderable height of 700 meters; to the south of Tripoli it supports some recent volcanic cones.

The Cretaceous zone is continued eastwards through the Hamada el-Homra and the Black mountains to the Libyan plain; it reappears on the eastern side of the great sea of sand, and forms the underlying rock of the oases Farafrah, Dachel, and Chargeh; on the northern side of these it is covered by the next zone, and then expands till it attains an enormous

[1] G. Stache, Fragmente einer afrikan. Kohlenkalkfauna aus dem Gebiete der West-Sahara; Denkschr. Akad. Wiss. Wien, 1883, XLVI, pp. 369–418, plate.

[2] Beyrich, Bericht über die von Overweg auf der Reise von Tripoli nach Murzuk und von Murzuk nach Ghât gefundenen Versteinerungen; Zeitschr. deutsch. geol. Ges., 1852, IV, pp. 143–161, in particular pp. 159, 160.

breadth in the south. Here, and as far as the north of Kordofan, it appears to rest everywhere directly against the Archaean complex.

In the valley of the Nile it extends as far as the ruins of Thebes, but to the north of this it is reduced to a narrow belt, running along the western margin of the ancient rocks which separate the Red sea from the valley of the Nile. To the north of the monastery of St. Paul it reaches finally the shore of the Red sea.

Throughout its extension in the east this zone presents at the base a formation, known as the 'Nubian sandstone,' which I have here, in accordance with Zittel and the earlier publications of Lartet, assigned to the Cenomanian, while further to the east, as we shall see later, deposits have been designated by this name, which are probably of more ancient date.

The Cretaceous area is thus narrow in the middle region of the Sahara and extremely broad in the east; but since Rohlfs has recorded 'Cornua Ammonis' on the way to Lake Chad, far to the south, even beyond Garo in the oasis of Bilma, it is possible that some of the relics of table mountains which are met with in that direction are not Devonian but Cretaceous in age [1].

The *fourth zone* is formed of Nummulitic limestone. Although this contributes to the formation of the mountain chains north of the Shotts, it is not known anywhere in the western and central Sahara, and only reappears in Egypt.

This zone rises from the sandy desert between the oases of Siwah and Farafrah, includes the oasis of Beharieh, where it is broken through by an isolated boss of basalt, and forms both the shores of the Nile from the Mokattam near Cairo to beyond the first cataract, where the Cretaceous zone, and below this, the Archaean rocks, crop out from beneath the Nummulitic limestone.

Against this fourth zone, the western part of which is completely buried beneath the sandy desert, the second Mediterranean stage rests, and forms as it were a *fifth zone.* It appears in the oasis of Siwah, and is continued thence to the north-east; it is not observed in the valley of the Nile, but reappears to the east of this, and reaches the Red sea at a point to the south-west of Suez. Certain observations seem to indicate that the Cyrenaica also consists of these deposits [2]. The remains of Mediterranean beds with *Ostrea longirostris* in the Shotts west of Gabes have already been mentioned.

*South Arabia and Abyssinia.* We have now followed the arrangement of the stratified rocks which underlie the desert region of North Africa, and we have seen how its Archaean foundation crops out between the Nile

[1] Rohlfs, Quer durch Afrika, I, p. 269.

[2] Zittel, Libysche Wüste, p. cxxxi, note 2.

and the Red sea. The question now arises, whether the deposits of the desert tableland really terminate here or whether they are continued further to the east. In order to ascertain this, we will first consider the regions which lie beyond the southern end of the Red sea, and afterwards those which lie beyond its northern end.

The first of these tasks is rendered comparatively easy by Carter's description of the coast of south Arabia. From this we borrow the following facts[1]:—

The Ras Mussandum, in the straits of Ormuz, often mistaken for basalt, consists of horizontal beds of dark limestone. From this point the mountains rise gradually to a considerable height, so that above Muscat they reach an elevation of 6,000 feet, and there are some even higher; among these appears for the first time the white Nummulitic and Alveolina limestone, which in the following stretches of the coast attains considerable importance. The town of Muscat is built on a green diallage-bearing rock which is described as euphotide; diorite has also been observed. The white limestone is continued towards the east; in the cliffs of the Wady Shab it is horizontally bedded; towards Ras el Hadd the height diminishes and this eastern promontory is merely a flat sandy spur.

The green rocks of Muscat reappear in the Ras Djibsh; the coast becomes quite flat and the sands of the desert finally reach the sea; so that from the island of Masira, which lies opposite and is about 600 feet high, a wide view of the interior is obtained. This island consists of the same green rocks, on which here and there patches of white Nummulitic limestone repose.

On the mainland the richly fossiliferous Nummulitic limestone now emerges from beneath the desert; it forms the west side of the bay of Haschish and the small island of Hammar el-Nafur, and extends nearly as far as Ras Djesireh.

This promontory again consists of the green rocks of Muscat; to its right and left extend, as far as the eye can reach, horizontal beds of light-coloured Nummulitic limestone. Of these the Ras Shiribedat is also formed. In the background of the bay of Kuria-Muria, which next succeeds, a black eruptive rock emerges, and dykes proceed upwards from this into the white beds of the Cretaceous.—

We have here reached an important boundary. From Ras el Hadd the cliffs along the coast do not exceed moderate heights, but now

[1] H. J. Carter, Memoir on the Geology of the South-East Coast of Arabia; Journ. Bombay Branch Asiat. Soc., 1852, IV, pp. 21–96. Among other works on this coast we may mention W. T. Blanford, Note on Maskat and Massandim, Rep. Geol. Surv. Ind., 1872, V, pp. 75–77. In this work it is suggested that the dark limestone of the straits of Ormuz may belong to the Trias; Myophoria is quoted as occurring here, but also Exogyra, so that the facts are contradictory.

the land rises suddenly from Ras Nus to a height of about 4,000 feet, and, with the exception of a single interruption just before Ras Fartak, continues at a very considerable elevation as far as the straits of Bab el Mandeb.

Here, too, granite appears for the first time. It forms the Kuria-Muria islands, where it is accompanied by the green rocks of Muscat; isolated patches of Cretaceous deposits overlie it. On Ras Nus itself the granite rises to a height of 1,200 feet: but its upper part is formed of limestone. From this point the surface of the granite slopes down, and near Morbat it is covered by a well-defined succession of strata.

The first member of the series is formed of yellowish and brown micaceous sandstones, about 1,700 feet thick, and without organic remains.

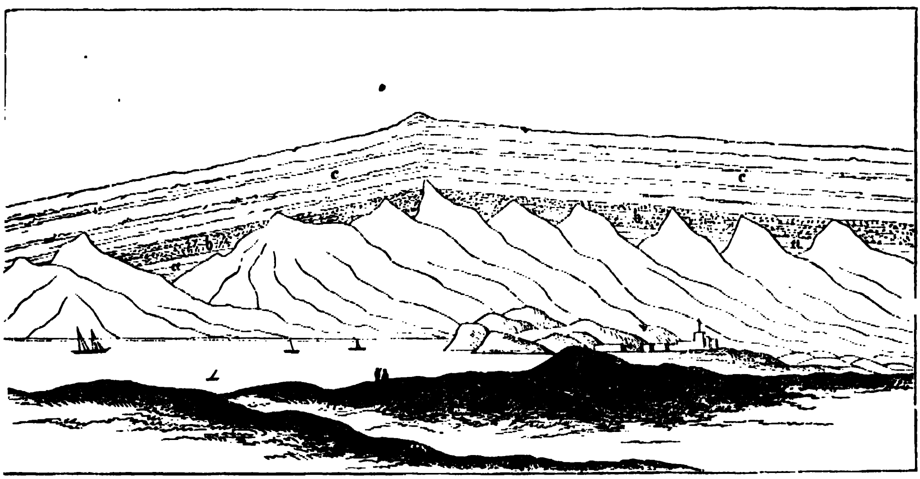



FIG. 42. *Morbat on the south coast of Arabia* (after Carter).
In the foreground granite; at the foot of the mountains recent marine deposits; *a*, sandstone for the greater part concealed by slopes of débris; *b*, variegated fossiliferous marl of the Cenomanian; *c*, upper Cretaceous limestone.

This is followed by a series of red or variegated clays 300 feet in thickness, which are frequently repeated in the succeeding stretches of the coast, where they have furnished *Pecten quadricostatus*, *Salenia scutigera*, *Orbitulina concava*, and other well-known Cenomanian species[1].

The beds of limestone which next succeed belong to the Cretaceous system, and on these rest, still higher, ramparts of Alveolina limestone, broken up into pillars. They are not represented on Fig. 42.

The lower sandstone of Morbat thus corresponds, both in structure and in position, to the Nubian sandstone of Egypt, and the sequence of strata

[1] P. M. Duncan, A Description of the Echinodermata from the Strata on the South-Eastern Coast of Arabia, and at Bagh on the Nerbudda; Quart. Journ. Geol. Soc. 1865, XXI, pp. 349–363.

observed by Carter at this point is the same as that met with near Assuan, for example, in the valley of the Nile.

In the lofty promontory of Ras Shejer the granite has disappeared; the sandstone also lies, in part, beneath the sea; and above the variegated argillaceous series rises in white cliffs the Cretaceous limestone.

Now follows in the bay of El Kamar the already-mentioned interruption of the lofty mountain slopes, but at Ras Fartak the plateau recommences. On this promontory we first see the beds of white Alveolina limestone rising obliquely from the sea to a height of about 1,900 feet; they then become horizontal and continue so as they extend further. In like manner, on the other side of the promontory, the beds of the variegated Cenomanian series rise at an angle of forty-five degrees and assume at a certain height a horizontal position. Near Ras Sharwain the basalt makes its first appearance as an intrusion into the variegated marls of the Cenomanian.

A narrow plain now inserts itself between the shore and the high cliffs, and on this several small volcanic cones appear between Ras Sharwain and Mokalla. Owing to their black colour and the sharply defined outlines of their lava-flows they stand out in striking relief against the white surface of the strand; they extend for a distance of about seventy-two kilometers.

In Mokalla granite reappears, accompanied by the green rocks and overlaid by the limestone; the edge of the great tableland rises to a height of 6,000 feet; the granite is exposed along the coast.

About ninety-six kilometers to the north-east of Aden, the deep sea washes against the foot of a mighty precipice, which rises thousands of feet above it; this continues for a distance of about forty kilometers; the precipice then runs inland in a straight line as far as the straits of Bab el Mandeb, so that a flat triangular space is left in front of it. On this stands a volcano, the crater of which rises to a height of 1,700 feet, and in the crater lies the town of Aden.

The coast of Somaliland, which lies opposite in the south, presents the same structure. The country to the east of Berbera consists of light-coloured limestone; on Hais an amphibolite rock crops out below this; Meid again is composed of light-coloured limestone, which probably extends without interruption as far as Cape Guardafui [1].

The island of Abd-el-Kuri is 1,600 feet in height; granite and the green rocks of Muscat form its base, over them lies limestone. In the

[1] Vélain's description, Mission de saint Paul, 4to, 1879, pp. 1–92, does not seem to me opposed to the older view, that Aden is really an eruptive centre. The limestone formations probably extend inland as far as the upper Juba in the country of the southern Galla: R. Brenner's Forschungen in Ost-Afrika, Petermann's geogr. Mitth., 1868, p. 365.

island of Tol-Faraun, 400 feet in height, only gypsum has been observed; the 'Brothers' between Abd-el-Kuri and Socotra are composed of the same rocks as Abd-el-Kuri, and according to B. Balfour's collections this is, in all probability, also true of the great island of Socotra itself[1].

In the north of this island a long band of ancient rocks, such as granite, gneiss, and hornblende schist, appears; it includes the Jebel Huggir, and is distinguished by the varied forms of its mountains; the whole of the south-west and east of the island is formed of hard, light-coloured, flat-lying limestone. In the east a rhyolitic region occurs, and smaller exposures of basalt are met with at various places.—

Thus the sedimentary formations on the south-east coast of Arabia are just as flatly bedded as in Egypt, and it is only locally, as, for example, near Ras Fartak, that bending is to be observed, and this appears to be due rather to slipping along a fault than to folding. As in Egypt again, there is no indication whatever, apart from the Nubian sandstone, of deposits older than the Cenomanian. Once more as in Egypt, the Archaean foundation crops out in many places, and the stratified sequence, at least as far as the granite zone of the Ras Nus and the Kuria-Muria islands, is precisely the same in both regions. Further to the east, in Oman, the only fact with which we are as yet certainly acquainted is the transgression of the Nummulitic limestone over the ancient rocks.

The coast regions in the north of Somali and as far as Socotra present the same structure, and we are thus led to recognize in the gulf of Aden a sunken area which interrupts the continuity of the tableland; while Arabia and Somaliland appear as the continuation of the great desert plateau of North Africa.

The eruptive rocks which were mentioned as occurring to the west of Ras Sharwain are only the forerunners of that important volcanic region, which forms the neighbourhood of the straits of Bab el Mandeb, and continues thence into many islands of the Red sea, and along its shores on both sides. The indications of comparatively recent eruptions increase rapidly towards the west. The mountains of Abyssinia and Shoa represent one of the most important regions of eruptive activity. It is possible that the extensive lava-fields of Abyssinia are not all of the same age; some of them may indeed, as Blanford thinks, correspond to the flows of the Deccan, and thus date from the beginning of the Eocene period; in any case it is certain that they are underlaid in most of the great valleys by horizontal beds of sandstone, which rest on an Archaean basis.

[1] B. Balfour, Report Brit. Assoc. 1881; T. G. Bonney, On a Collection of Rock Specimens from the Island of Socotra, Phil. Trans. 1883, CLXXIV a, pp. 273-294, pl. vi, vii.

This appears not only from the works of Ferret and Galinier[1] in the case of Abyssinia, and those of Rochet d'Héricourt[2] in that of Shoa, but above all from the observations of Blanford, who during the English expedition into Abyssinia studied the section from Massowah to Magdala in great detail[3].

Near Antalo, in the north-east of Abyssinia, a formation is represented which is nowhere else to be met with in the great desert plateau, i. e. the middle Jurassic, a patch of which had been identified by its organic remains; this is Blanford's Antalo limestone. Unfortunately, as this conscientious observer himself points out, it has not been found possible to establish with certainty the relative position of the sandstone and the Jurassic limestone[4]. It is therefore uncertain whether the probable representative of the Nubian sandstone, Blanford's sandstone of Adigrat, is to be assigned to the Cenomanian, or whether it is one of those doubtless older sandstones of which I shall have to speak directly.

*Sinai and Syria.* The massive rocks which form the foundation of the great desert tableland, the Nubian sandstone, and the thick Cretaceous and lower Tertiary limestones are continued, as we have seen, from Africa eastwards into the south of Arabia. Their connexion with the mountains of the Sinaitic peninsula, the Promised Land, may be yet more clearly recognized.

The narrow zone of ancient massive rocks which runs northwards between the Nile and the coast of the Red sea, known to antiquity as the *Mons porphyrites*, presents a great diversity of lithological character, and this also distinguishes the same rocks further to the east. Red granite plays the chief part; it is accompanied by gneiss and many kinds of ancient schist, as well as by red porphyry and diorite. The rocks extend to the shore of the gulf of Suez, and are thence continued on the opposite coast in those lofty heights which occupy the southern part of the Sinaitic peninsula, where they are dominated by Jebel Musa, the 'Mountain of the Law.' They thus reach the east coast of the peninsula, and are again similarly continued on the other side of the gulf of Akabah in the granite mountains of the land of Midian, and to the north and south of this range.

[1] Ferret et Galinier, Voyage en Abyssinie, III, Géologie. All the older observations on this volcanic region have been collected together by T. E. Gumprecht, Die vulcanische Thätigkeit auf dem Festlande von Afrika, in Arabien, und auf den Inseln des Rothen Meeres, 8vo, Berl. 1849, pp. 103–193.

[2] Rochet d'Héricourt, Bull. soc. géol. de Fr., 1846, 2e sér., III, p. 541 et seq.; Second voyage dans le pays des Adels, 8vo, Paris, 1846; Dufrénoy, Rapport, Comptes rend., 1846, XXII, p. 806 et seq.

[3] W. T. Blanford, Observations on the Geology and Zoology of Abyssinia, 8vo, Lond., 1870, pp. 143–203 and geological map.

[4] Blanford, op. cit., p. 177, note.

Many circumstances have contributed of late years to increase our knowledge of this district; as, for example, Burton's attempt to prove the existence of a rich gold-field in Midian [1], and Beke's doubts as to the true position of the Biblical Sinai. Jebel Baghir or Jebel el Nûr, 'the Mountain of the Light,' which lies to the north of Akabah on the west side of the Wady Ithm, was said to be in reality the consecrated spot; Milne, who accompanied the Biblical explorer, has described the structure of the eastern coast of the gulf [2]. Thus we reach the neighbourhood of Petra and Hor, and with them the scene of the valuable researches carried out by L. Lartet. These have thrown so much light on the structure of Palestine and Idumaea [3], that, taken in connexion with the clear descriptions of Judaea furnished by Oscar Fraas [4], they enable us to arrive at definite conceptions regarding the structure of the valley of the Jordan, and its relations to the Red sea. For the present, however, we will only borrow from Lartet's observations the important fact that the massive rocks extend further to the north on the east than on the west side of the Wady Arabah, a valley which forms the prolongation of the line of the Jordan and the Dead sea. The porphyries, which appear to be the most recent of these rocks, play an important part in the structure of Mount Hor in the north, and their last offshoot in that direction is to be seen near Safieh on the south-east shore of the Dead sea.

Thus ancient massive rocks surround the whole northern region of the Red sea. At the southern point of the peninsula of Sinai lies the intersection of two of the greatest systems of linear fractures which are known on the surface of the earth. The first is that of the Red sea (the Erythraean system), which is continued in the direction of Suez. The second, which runs almost directly from north to south, is that of the Jordan. This extends from Coele-Syria, through the lake of Tiberias, following the course of the Jordan, through the Dead sea and the Wady Arabah, over the threshold of Safeh (which is about 230–240 meters high and formed of Cretaceous limestone), down to the Wady Akabah and the gulf of the same name. It meets the line of the Red sea at an acute angle and is *not continued* further. The intersection takes place within the region of the ancient massive rocks, which is consequently divided into three parts.

[1] R. F. Burton, The Gold-Mines of Midian and the ruined Midianite Cities, 8vo, Lond., 1878.

[2] J. Milne, Geological Notes on the Sinaitic Peninsula and North-western Arabia; Quart. Journ. Geol. Soc. 1875, XXXI, pp. 1–28.

[3] L. Lartet, Essai sur la géologie de la Palestine et des contrées avoisinantes, Ann. des sciences géol., 1869, I, pp. 1–116, 149–329, and map; Exploration géologique de la Mer Morte, de la Palestine et de l'Idumée, 4to, Paris, 1877; this volume forms part of the Expédition scientifique du Duc de Luynes.

[4] O. Fraas, Aus dem Orient: geol. Beobachtungen am Nil, auf der Sinaï-Halbinsel und in Syrien, 8vo, Stuttgart, 1867.

The first and western part is the *Mons porphyrites* and the coast range of Egypt. The second is the Sinaitic region, which is wedge-shaped. The third part is the Arabian, the last traces of which are to be seen beyond Mount Hor even as far as the Dead sea.

This group of ancient rocks, which on account of the presence of porphyries and diorites I will not in their entirety designate as Archaean, is followed by the Nubian sandstone. This begins as a narrow band only, forming the western border of the ancient mountains in the east of Egypt; it runs from their northern end to the sea, and broadening out crosses the peninsula of Sinai; it is largely covered with sand, resulting from its own disintegration. It seems to end suddenly near the northern end of the gulf of Akabah, but reappears to the east of the line of the Jordan, lying partly below in the valley in faulted-down fragments, partly up on the tops of the mountains: thus Milne found two great masses of sandstone above the granite at an altitude of about 1,000 meters, forming the highest parts of the Jebel Atagtaghir, not far from the 'Mountain of Light'; and according to Lartet the same Nubian sandstone forms the summit of Mount Hor. This is the site of Aaron's grave, 1,327 meters above the Red sea: the sandstone here rests on porphyry.

From Mount Hor the sandstone sinks downwards and then forms the basement of the cliffs on the whole of the east side of the Dead sea, while on the west side it is not visible. The difference in height between Mount Hor and this exposure amounts to 1,720 meters. For a considerable distance to the north the Nubian sandstone crops out again, but only at the foot of the eastern slopes of the valley of the Jordan; it probably finds its continuation in the red sandstone of Mount Lebanon.

In this region the sandstone certainly cannot be at once assigned to the Cenomanian, as was the case in the west. In the first place we may remark that, apart from less certain observations, the Carboniferous has been recognized by Bauermann and Tate in the Wady Nasb of the peninsula of Sinai. Marine deposits are represented there by limestone with *Orthis Michelini* and other Carboniferous fossils, and the impression of a Lepidodendron has been found in the sandstone[1]. This is an indication of the reappearance of that Carboniferous zone which Lenz on his journey to Timbuctu encountered in the far west, where it is represented by marine beds; it is the same zone which has been recognized in the neighbourhood of Murzuk by its plant remains, and of which no trace has as yet been found in the district of the Nile.

In general, however, the characters of this sandstone recall in a most striking manner the Permian sandstone of Europe. The Nubian sand-

[1] R. Tate, On the Age of the Nubian Sandstone, Quart. Journ. Geol. Soc., 1871, XXVII, pp. 404–406; Pomel, Bull. soc. géol. de Fr., 1876, 3e sér., IV, pp. 524–529.

stone is here frequently dark red in colour, or white, or red and white; it often rests on porphyry, contains rolled fragments of this rock, and according to Raboisson is even traversed by dykes of porphyry[1]. On the peninsula of Sinai, as for instance near Petra, it contains copper; at some localities turquoise is found in it, both on this peninsula and in Abyssinia; salt and gypsum also occur. From the examination of a piece of fossil wood, found by Russegger in the neighbourhood of Assuan, Unger came to the conclusion, as early as 1858, that the Nubian sandstone is contemporaneous with the Rothliegende. This result has not been confirmed by Zittel, who, on the contrary, has established its more recent age by the discovery of other plant remains found in the north[2]. But in the east, as well as in Abyssinia, the number of outward indications which bear witness to the higher age of the greater part of the Nubian sandstone increases to such an extent that the question must still be considered open.

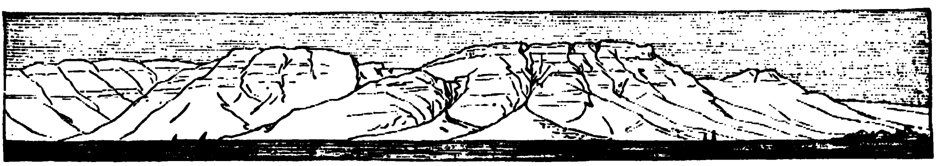


FIG. 43. *Jebel Atáqa near Suez.*

The sandstone is everywhere covered by the Cenomanian, together with the deposits, for the most part calcareous, which succeed it, up to the Nummulitic limestone; these will be discussed presently. If the Nubian sandstone is Cenomanian, then an interval of incalculable length must lie between it and the Carboniferous beds of the Wady Nasb. If it belongs to the period of the European Rothliegende, then the interval which precedes the transgression is only diminished by a fraction and the resemblance to those regions where the Cenomanian rests on the Rothliegende (Bohemia, for example) is increased.

The zone of Cretaceous and Nummulitic limestone extends from Cairo towards Suez, and there forms the heights which coming from the west approach the southern part of the Canal and the northern part of the gulf. One of these is Jebel Atáqa, formed of numerous horizontal beds, ending in precipices, which rise broad and bluff above Suez. It is traversed, as was shown by Vaillant, by a fault with a throw of about 300 meters[3]. I entirely concur with Beyrich in regarding the form of this

[1] L'Abbé Raboisson, Contribution à l'histoire stratigraphique du relief du Sinaï, et spécialement de l'âge des porphyres de cette contrée; Compt. rend., 1883, XCVI, pp. 282-285.

[2] Zittel, Libysche Wüste, p. lix.

[3] Léon Vaillant, Note sur la constitution géologique de quelques terrains des environs

mountain as determined by parallel fractures, a view which is supported by the local occurrence of small volcanic cones [1].

The Cretaceous and Eocene beds now proceed, as does the Nubian sandstone on which they rest, across the peninsula of Sinai: in front of them extends the desert of Tih. Bauermann has shown that they are here intersected by a large number of faults [2].

They now reach Palestine and form for a great distance the mountains of Judaea and the whole country as far as the spur of Carmel; then follows the subsidence of Jezreel with its volcanic eruptions, and on the other side the same beds extend into the Lebanon. Almost the whole country is formed of Cretaceous limestone, on which a few isolated patches of Eocene limestone repose. To the east of the Jordan the structure is slightly different. At the bottom of the Wady Garundel, to the south of Petra, lies a downthrown fragment of Nummulitic limestone, and in several other localities the Cretaceous is likewise faulted down; at the same time patches of Cretaceous appear on the heights. Of the three peaks of Mount Hor, one consists of porphyry, another, the highest, of Nubian sandstone, as we have already seen, and the third of Cretaceous limestone. To the north the same white limestone forms the whole of the highland of Moab and Ammon to the east of the Dead sea. Below the limestone the Nubian sandstone may be seen on the margin of the sea; on the heights above it is crowned by black volcanic masses, isolated cones, and broad lava streams. Further on, the white limestone forms the east side of the Jordan valley, and finally disappears beneath the broad sheets of lava of the Jaulan, the Hauran, and the other volcanic regions discovered further in the interior by Wettstein and Doughty.—

The traveller who crosses the country from Jaffa to Jerusalem and journeys on to the Dead sea first ascends the ridge of Judaea to a height of 1,000 meters above the Mediterranean, and then descends about 1,400 meters to the Dead sea, the waters of which stand, as is well known, at a level of −392 meters. Since, however, the depth of the Dead sea close to the east coast is nearly 400 meters, the total fall of the surface from the ridge of Judaea to the lowest point of this great line of subsidence amounts to about 1,800 meters.

The researches of Lartet, the investigation of the Cretaceous threshold

de Suez, Compt. rend., 1864, LIX, pp. 867, 868, and Bull. soc. géol. de Fr., 1865, 2e sér., XXII, pp. 277–286.

[1] E. Beyrich, Ueber geognostische Beobachtungen G. Schweinfurth's, Sitzungsber. Akad. Berlin, 1882, X, p. 175. An exposure of volcanic rocks near Abu Zábel on the Fresh-water Canal has been described by Beyrich and Arzruni, tom. cit., pp. 177, 182, pl. v. Figari Bey marks on his geological map a large number of these points in Arabia Petraea, but these have not been confirmed.

[2] H. Bauermann, Note on a Geological Reconnaissance made in Arabia Petraea in the spring of 1868; Quart. Journ. Geol. Soc., 1869, XXV, pp. 17–39, pl. i.

of the Wady Arabah, which, rising to a height of from 230 to 240 meters, forms the watershed between the Red sea and the Dead sea, and the now demonstrated complete absence of upper Tertiary deposits in the whole region of the subsidence, have fully established the fact that the open sea has never penetrated into this great and remarkable rift. The formation of this depression is a recent event, otherwise the sea would have crossed the threshold of the Wady Arabah.

The whole country to the west of the Dead sea is horizontally stratified, and in spite of the stupendous descent of the surface it consists only of middle and upper Cretaceous limestone. According to Fraas, however, there exist on both sides of the ridge, on the Mediterranean side as on that facing the Dead sea, parallel step-faults, along which the surface sinks from the mountain heights to the depths of the sea on the east and on the west[1].

On the east of the Dead sea the case has changed. Lartet has shown that on this side the ancient massive rocks advance further to the north than on the west, that the porphyry still crops out on the south-east side of the Dead sea, and that the Nubian sandstone may be seen at the foot of the slopes along the whole length of the east coast and far up the valley of the Jordan. A transverse section, wherever taken, will therefore show older rocks on the eastern than on the western shore. This led Lartet to conclude, in accordance with the earlier suppositions of L. v. Buch and Hitchcock, that the Dead sea and the line of the Jordan represent a *fault with a downthrow on the west side.*

If we now compare Lartet's observations to the east of the fracture with those of Fraas to the west of it, we shall obtain the following results. The height of the broad ridge of Judaea does not differ much from that of the highlands to the east of the Dead sea. In both places the ground is formed of Cretaceous limestone. The line of the Jordan is a fracture, but whereas in the east this fracture finds its consummation in a single great fault, in the west it is represented by several parallel faults, along which the western side has sunk not as a whole but in steps, and thus *an asymmetric trough has resulted.*

The ridge of Judaea has retained its height and the step-faulting is repeated towards the Mediterranean; *but here every trace of the opposite side of the fault is lost.* And since there is no vestige of Mediterranean deposits of Tertiary age on the whole of the Syrian coast, with the exception of the low and recent littoral deposits of Beyrout and Jaffa containing *Pectunculus violascens*, this fracture must also be considered as very recent, almost as recent as the formation of the Aegean and the Black sea.

Of this we shall soon see further proof.

[1] Lartet only assumes a very gentle arching of the country of Judaea; I have followed the detailed statements in Fraas, p. 72 et seq.

Let us, however, return to the Dead sea.

A simple fault may produce a step at the surface, but not a valley; it may be widened out into a valley by erosion, but then this valley will possess a definite slope corresponding in direction to that in which the waters flow away, and it will never descend below the level of the sea. A valley, the bottom of which descends 800 meters beneath the sea and then a little further to the south ascends 230 meters above it, only to sink beneath it again, cannot have been formed either by a single fault or by faulting and erosion combined. Strips of land of great length must have subsided along parallel fractures and to unequal depths. This is another instance of that variation in the throw of faults which we have already observed in the lofty table-lands of Utah, and in the great fractures of the southern Alps. In this way alone can broad valleys such as the Wady Arabah and the Wady Akabah have been formed, and the unequal subsidence of different parts of the trough may have been caused by compression [1].

The Red sea itself is, however, also a trough-subsidence, probably the greatest in the world. The parallelism of its coasts, the similarity of the opposite shores (so far as they are known), and the volcanic phenomena in the south all point to this conclusion. This basin, especially its southern part, has already often been characterized as a 'collapsed area'; but the most felicitous comparison is by Oscar Fraas: 'Just as the Schwarzwald and the Vosges, although separated by the broad valley of the Rhine, bear witness to an original organic unity, so too do the crystalline mountains to the east and west of the Red sea. . . . As on the west of the Vosges and the east of the Schwarzwald the Trias and Jurassic rest against the old crystalline complex, so too do the upper Cretaceous and the lower Tertiary on the east of Mount Sinai and the west of the mountains of the Nile [2].'

[1] With regard to the time of the down-break and the formation of the trough-fault of the Dead sea the following facts may be mentioned. Up to a height of about 100 meters, that is, 292 meters below the Mediterranean, the Dead sea is surrounded by very recent alluvial beds which Lartet calls the 'Dépôts de Liçan.' They lie horizontal and thinly stratified, and contain gypsum, but neither organic remains nor traces of volcanic rocks, although the eastern flank is covered with basaltic eruptions. Lartet concludes that the fracture is older than these eruptions, and distinguishes among the lavas those which are older and extend on the heights in a tabular form, and those more recent, the streams of which lie in valleys recently produced by erosion. If the eastern border of the Dead sea has been so far explored that we may speak with some certainty of the absence of basaltic remains in the Dépôts de Liçan which occur there, a point on which I can give no opinion, we may further conclude from the horizontality of these deposits that none of the more recent eruptions were accompanied by any essential change in the chief area of subsidence. Earthquakes have, as is well known, continued up to the most recent times; on the Red sea several volcanic eruptions have occurred in historical times.

[2] O. Fraas, Aus dem Orient, p. 33.

Let us now consider the valley of the Rhine near Strassburg. The stratified plateaux of the sunken area of South Germany and those of the Paris basin, which were once united across the Schwarzwald and Vosges, have subsided; the horsts have remained in position, but they are cut through by the great trough of the Rhine, determined by rectilinear fractures. Whether these events were contemporaneous, or in what order plateau-subsidence took place at the sides and trough-subsidence in the middle, we do not know. But in just the same way the ancient mountains on the Red sea rise as a horst out of the Nubian sandstone and the Cretaceous and Eocene plateaux, and in just the same way this ancient horst is cut through the middle by the great Erythraean trough.—

Some facts suggest the possibility that the great Wady Serhan in North Arabia, and particularly its southern part the Jowf, is also a trough-subsidence; Blunt has already compared this region to the Dead sea[1]. The volcanic rocks of the Hauran are continued west of the Wady Serhan for an unknown distance to the south; in the east, latitude 31° appears to mark their southern boundary. Beyond this lies an extensive region of sandstone, with beds outcropping in successive steps, as in the Sahara; this sandstone forms the whole of the stony Hamada as far as the Euphrates. The highest part of the region, about 2,500 feet high, lies close to the east edge of the Jowf, and terminates in a fairly steep cliff above this plain, which is 600 feet below. On the flat sandstone plateau rests a sharply circumscribed sandy desert, the great Nefud; from this rise humps of sandstone which are as remarkable for their blackened surface as those of the Tazili in Africa. Humps of sandstone also occur to the south of this sandy desert, till finally on Jebel Aja, to the west of Haïl, and on Jebel Schomar, the underlying granite makes its appearance. Red granite predominates, and these mountains may be regarded as a continuation of the heights of Sinai.

This description by Blunt also confirms the supposition, that as Syria in the north, and the land of Oman and the coast of Arabia in the south, so the whole interior of the country possesses a structure similar to that of Egypt and the desert region of North Africa.

Thus in the whole of the desert from the coasts of the Atlantic to the gulf of Gabes; then southwards through the country of Tuareg to beyond Air, far south of the oasis of Kawar, to Borgu, to Dar-Fur and even into Somaliland; then in the north—the whole of Egypt, of Syria, and the whole of Arabia as far as the Euphrates—we see a great segment of the

[1] W. Scawen Blunt, Notes on the Physical Geography of Northern Arabia, in Lady Anne Blunt, A Pilgrimage to Nejd, 8vo, 1881, II, pp. 235-248. From Doughty's description of western Arabia, which has just appeared, it seems probable that the granite of Haïl extends to the south-west as far as Mecca; this work shows for the first time the great importance of the volcanic Harras: Travels in NW. Arabia and Nejd, Proc. Geogr. Soc., 1884, pp. 365-399, and map.

earth's crust distinguished by the possession of a number of characters common to the whole. Throughout this region flat bedding predominates; disturbances occur only in the form of subsidence, particularly as great trough-subsidences, which are here and there associated with flexure of the edges. On the other hand tangential movement and folding are entirely absent, at least as far as we can judge at present; and as well, according to the present state of observation, the whole series of deposits which extend from the close of the Palaeozoic aera to the Cenomanian stage are also wanting, with the exception of the Antalo limestone in Abyssinia; and if the objection be raised that these vast plains have been so little explored that we can scarcely attach importance to negative characters of this kind, yet we must remember that in central Sahara, in Egypt and Palestine, the transgression of the Cenomanian stage, which rests directly on Palaeozoic or even older rocks, has been established with certainty over large areas.

The great desert platform thus extends from the Atlantic Ocean as far as the Euphrates and the Persian gulf, and the lie of the beds as well as their sequence are distinguished by the same characters as in the Russian Platform.

*Suez and the Nile.* The Erythraean trough is filled up in the north by the isthmus of Suez, a narrow low-lying strip of recent alluvial deposits. In spite of its trifling age and its insignificant height this district separates two distinct marine faunas from one another.

The fauna of the Indian Ocean enters the Red sea by the straits of Bab el Mandeb, many of its typical species reach the gulf of Akabah, it is represented near Suez, and even penetrates inland above Suez into a series of isolated basins, the so-called Bitter lakes, which are now intersected by the Canal. The shores of the Red sea present in many places, both in the south and in the north, traces of a higher level of the strand-line. Even after the formation of the great trough, the strand must have stood at a higher level and have been lowered subsequently. The indications of this consist as a rule of horizontal beds of recent shells or of coral growths now laid dry; they even occur near Suez itself.

The Lusitanian fauna of the Atlantic coast forms, as we have seen previously, the characteristic part of the marine Mediterranean fauna, but it contains a large admixture of Celtic relict species and a few rare boreal, Arctic, and West Indian forms. Thus it extends, though not very richly represented, as far as the 'Lido' on the east coast of the Delta, and a few of its members, even before the construction of the Canal, lived in the lagoons of the interior, especially in the great lake Menzaleh.

How feebly this boundary, so important in the animal world, is expressed in the relief of the ground may be seen from the fact that the highest ridge (El Guisr), which had to be cut through for the Canal, is only 18 meters high. In the Fresh-water Canal, which conducts the water of the Nile to Suez, and follows in part the line of the old Fresh-water Canal of the

Pharaohs, the river reaches Ismailia near the middle of the isthmus at a height of 6·7 meters above the level of both seas. Even before the Canal established communication between these seas wells were to be seen far inland, the waters of which rose and sank with the tides, and it is not unlikely that just as the Rhine and Danube communicate underground in a common body of subterranean water, so do the Red sea and the Mediterranean, and they have probably always been united by a common subterranean sheet of brackish water.

The total length of the Canal measures 160 kilometers; but if we deduct from it the lagoons and the isolated arms of the sea, which penetrate into the country both from north and south, then the breadth of the dividing isthmus is at once reduced to less than 30 kilometers, or even to 20 or 15 kilometers, if we take into account the beaches of bleached shells which appear here and there on the lower slopes.

The Canal penetrates the narrow sandy 'Lido' near Port Said and enters lake Menzaleh; the mouths of the Tanitic and Pelusian (or Bubastic) branches of the Nile lie to the east of this point. All the marshy land to the east as far as the ruins of Pelusium is being rapidly silted up. The Canal intersects the line of the ancient Pelusian branch at kilometer 37; it then traverses a narrow stretch of dry land near Kantara and reaches lake Balâh, the last lake of the Mediterranean region, which extends southwards from El Fardân to about kilometer 66. It is not till we have reached this point that we leave the Mediterranean region.

We now cross the ridge of El Guisr and arrive at lake Timsâh, i.e. the lake of Crocodiles, which the Canal intersects between kilometers 76–80. On the shore of this lake lies the modern town of Ismailia, and to the west of it we meet the Fresh-water Canal near Saba'h 'Byar, i.e. The Seven Springs. This point corresponds to the entrance of the valley of Gessen, and, as we shall see directly, to the course of a branch of the Nile, which once flowed in the direction of lake Timsâh.

The flat country to the east and south-east of lake Timsâh bounds the lake in cliffs, which are preceded by a few small tabular masses; among these I may mention the plateau of Hyenas in the east, that of Tussûm at kilometer 85, and near to it the place called Sheich Ennedek.

To the west of Tussûm a large group of dunes occurs which runs to the south-south-west, and at kilometer 90 we reach the Serapeum. A little to the south of this point, at about kilometer 94–95, begin the two great basins of the Bitter lakes, which before the opening of the Suez Canal lay almost dry. They coincide with the Canal as far as kilometer 138, and the whole of this area beginning at Serapeum belongs to the Erythraean region. We now cross the threshold of the Shalûf, and through a narrow furrow in which lies the ancient canal of the Pharaohs we reach the gulf of Suez at kilometer 150, and at kilometer 160 the Red sea.

It is only in the southern part that this line is approached from the west by true mountains; these are Jebel Genéf, in the prolongation of which lies the ridge of Shalûf, bounding the Bitter lakes on the south, then Jebel Auwebed, and the long ridge of Jebel Atáqa, which, south of Suez, meets the Red sea in a broad steep cliff (Fig. 43).

Neither the widely exposed structure of these mountains, nor that of the flat country, presents any indication of bending or up-tilting of the strata. Faults, it is true, may be seen in the mountains; the marine strata of the plain look as though they had only yesterday emerged from the sea.

In 1869 the Khedive Ismail afforded me the welcome opportunity of examining the most important sections of the Canal. But the local observations which I then made were first brought into organic connexion through the excellent works on the isthmus which have since appeared; among them I will mention especially those of Laurent[1], Lesseps[2], and T. Fuchs[3]. But I carried away a deep impression of a region in which the succession of marine formations may be seen, as they were deposited from very remote times, in beds which are still almost or quite horizontal. Two series may be observed in these horizontal sediments, namely, an older series, in which the strata *overlie each other* normally, and the beds decrease in age as we ascend the mountains, so that the youngest lie on the summits of the table-lands; and a second more recent series, in which the strata *rest against* each other, so that the deposits descend in successive steps which are lower in proportion as the deposits are more recent, so that finally the youngest members of this series lie at the level of the sea, and at the same time at the level of the oldest members of the first series. The second series was evidently deposited at a time when the coast-line was sinking and, it would appear, sinking rhythmically; the first or ascending series hardly furnishes any information on this point; but it is clear that with a subsiding strand-line a limit must be reached as soon as the level of the sea coincides with that of the sediments deposited in it. Finally the beginning of the second series presupposes, in this case, destruction of the preceding sediments and the consequent formation of new submarine slopes.—

Three regions may, as we have said, be distinguished without difficulty on the line of the Canal, namely, the Mediterranean region from kilometer 0–66, extending through lake Menzaleh to the south point of lake Balâh; the central or neutral region from kilometer 66–95, which includes

[1] C. Laurent, Essai géologique sur les terrains qui composent l'isthme de Suez; extrait de l'Annuaire 1870 de la Soc. des anc. élèves de l'Ec. imp. des Arts et Métiers, 8vo, S. Nicolas-de-Port, 143 pp. and 2 pl.

[2] F. de Lesseps, Communication sur les lacs amers de l'isthme de Suez, Compt. rend., 1874, LXXVIII, pp. 1740–1748; Deuxième note, op. cit., 1876, LXXXII, pp. 1133–1137.

[3] T. Fuchs, Die geol. Beschaffenheit der Landenge von Suez; Denkschr. Akad. Wiss. Wien, 1877, XXXVIII, pp. 25–42, 3 pl.

lake Timsâh; and the Erythraean region from kilometer 95–160, i.e. from a point to the south of the Serapeum through the Bitter lakes and the lagoon of Suez to the Red sea; but if we follow Laurent, who takes into account the banks of dead molluscan shells on the slopes, then the Mediterranean zone extends as far as kilometer 68, the neutral zone with lake Timsâh only to kilometer 83, and the remainder forms the Erythraean region. Let us also bear in mind that the valley of Gessen and the Fresh-water Canal coming from the Nile meet the line of the Suez Canal in the neutral region not far from lake Timsâh.

The country consists in short of the following elements: the higher mountains in the south-west, with the inconspicuous remnants of the second Mediterranean stage; the Erythraean deposits; the more recent deposits of the Mediterranean; the deposits of the Nile; and, finally, the dunes and spits and bars along the coast.

The loftier mountains, the mighty Atáqa near Suez, Auwebed and Genéf, must be regarded as part of the great limestone zone which extends to the peninsula of Sinai and to Judaea.

The oldest series visible is the middle Cretaceous; judging from the fossils which Beyrich cites from Auwebed, the succession of strata must there extend up to the Oligocene.

The second Mediterranean stage has already been discussed (p. 324), and it has been pointed out that it advances south of the Atáqa into the present region of the Red sea. Nevertheless, no considerable intermixture of the Mediterranean and Erythraean faunas has occurred. The Erythraean trough can therefore hardly have existed here in its present form at the time of the second Mediterranean stage. Beyrich even suggests that the Miocene deposits themselves may have been cut up, together with the mountain masses, by parallel fractures, i.e. that they were not deposited in the valleys in which we now find them, but that they are older than these valleys. They must then be assigned to the 'superposed,' not to the 'apposed' series of strata. This point is worthy of fresh investigation.

Of greatest interest are the recent deposits of the isthmus. It is obvious that with a strand-line only 18 or 20 meters higher than at present the existing isthmus would be submerged, and that in earlier times this submersion would have taken place with a strand-line at an even lower level, since a large part of the existing ridges of land is only composed of blown sand.

The first remarkable fact with which we are confronted is the relationship of the fauna, represented only by a small number of species, found in the sand deposits near the pyramids of Ghizeh, with that of the Red sea; this was first pointed out by Beyrich and subsequently recognized by T. Fuchs. These sand deposits form the cliff which bounds the desert towards the valley

of the Nile. The Sphinx is carved out of their consolidated beds. Zittel gives the height of the deposits as 64 meters above the sea, and Schweinfurth records the same height for the upper limit of a zone of Pholas borings, which he traced on the slopes of the Mokattam above Cairo and has recognized as belonging to this phase [1]. The shells of *Ostrea Forskali* and *Pecten erythraeus*, species which live in the Red sea, lie in this sand.

Thus a district of the Erythraean type, or at least one which includes several species characteristic of the Red sea, occurs in the region of the present Mediterranean.

We will now examine the isthmus.

T. Fuchs distinguishes two regions about the Bitter lakes: a lower-lying younger region with an undulating surface, which does not rise more than 8 meters above the sea-level, and behind this a terraced land with concentric cliffs. The highest point visited by T. Fuchs lay about 14 meters above the sea, but other steps further east probably attain double this height. The largest number of shells collected were obtained from the plateau of Kabret, lying about 8 meters above the surrounding desert and 5 kilometers to the east of the lake, on the first step of the terraced land. These are chiefly Erythraean marine Mollusca, but also include a few forms alien to the Red sea, among others *Ostrea pseudocrassissima*, which exactly resembles the well-known form of the Mediterranean Tertiary beds; two Pectens not known living; further, fresh-water Mollusca which now inhabit the upper Nile, such as *Aetheria semilunata* and *Spatha nilotica*, of which we shall have to speak later.

Thus the Erythraean fauna lies at a trifling height above the Bitter lakes, accompanied by a number of extinct types, of which one species at least is distinctively Mediterranean; at the same time we find the Mollusca of the Nile.

Let us now turn to the coasts of the Red sea.

Fresh observations by Hull, of which only a brief account is available, have shown that traces of an ancient sea-level may be seen near Suez about 200 feet above the existing sea; this very nearly coincides with the height of the Pholas zone near Cairo.

The accounts of the still younger and therefore lower-lying shell-beds near Suez are much more complete.

Issel has undertaken the important task of examining the organic remains of these beds and comparing them with the present fauna [2]. Although the beds lie only a few meters above the sea, are perfectly horizontal, and contain bivalves as a rule in their natural position, and

[1] G. Schweinfurth, Ueber die geol. Schichtengliederung des Mokattam bei Cairo; Zeitschr. deutsch. geol. Ges., 1883, XXXV, p. 716 et seq.

[2] A. Issel, Malacologia del Mar Rosso, 8vo, Pisa, 1869, p. 17, and Catalogo delle conchiglie fossile raccolte sulle spiagge emerse del Mar Rosso, pp. 245–303.

although some of the species still retain their original colour, yet this fauna is somewhat different from that which at present inhabits the gulf of Suez. Altogether 232 species were found in these deposits, and of these 18 genera and 105 species are no longer known in the gulf of Suez or in that of Akabah. On the other hand, 11 genuine Mediterranean species occur; and others will probably be found in more remote parts of the Red sea.

Without entering further into the details of this comparison we will merely point out that, even with a strand-line at such a trifling height above the existing sea, Mediterranean forms were able to mingle near Suez with the Erythraean fauna. We must, however, at once add that in the neighbourhood of Suez at the present day Erythraean types live in company with a not inconsiderable number of species, which are evidently representative forms of Mediterranean species, and often only distinguished from them by most trivial characters. Under these circumstances I do not hesitate to adopt Issel's view, and to consider these representative species as recently modified forms. They are of recent origin and have probably arisen through isolation. The renewed fusion of the two faunas, which has been rendered possible by the construction of the Canal, takes place slowly, as Keller has shown, and is almost entirely confined to the littoral forms[1].

Many circumstances seem to indicate that the subsidence of the strand-line has not been gradual, but periodic, as we shall explain more fully on a later page. Attempts have been made to prove from historic sources, and especially from the statements concerning the passage of the Israelites through the Red sea and the death of Pharaoh Ptah Men, that at that time the Bitter lakes communicated with the Red sea and were filled with sea-water; but new theories as to the site of the crossing have been put forward, and I do not venture to give an opinion on this question.

Lesseps has brought together the statements of Herodotus, Diodorus, Pliny, and Strabo with reference to the ancient history of the Fresh-water Canal. For us the fact is important that, as a glance at the description of Herodotus proves[2], the level of the Nile at the time of Necho, the son of Psammetich, was precisely the same as at present, for the line of the Fresh-water Canal of that time coincides for considerable distances with that followed by the Fresh-water Canal of to-day. Strabo relates that the Bitter lakes had become fresh owing to the Canal, and it is possible that this may afford an explanation of the fact quoted by Renaud, that according to the borings which were made in the bottom of the Bitter

[1] C. Keller, Die Fauna im Suez-Canal und die Diffusion der mediterranen und erythräischen Thierwelt; Neue Denkschr. Schweiz. Ges., 1883, XXVIII, 39 pp., 2 pl.

[2] Herodot., Euterpe, II, p. 157 et seq.

lakes the salt deposit, which is 7·5 meters deep in places, appeared to rest on mud derived from the Nile [1].

Diodorus states that Ptolemy II had constructed sluices to open and close the Canal; for this reason that part of the Canal which enters the sea near Arsinoë (Suez) was called the Ptolemaic river. Lesseps believes that they were afraid, on account of the trifling dimensions of the Canal in transverse section, that it might be invaded by the flood waters of the Red sea, and that the sluice was consequently a tidal gate. On the other hand, Lesseps points out that near the Shalûf the existing Fresh-water Canal is identical with the ancient one, and that the latter terminates at present in a sluice with a fall of 3 meters above the mean level of the Red sea. Eleven centuries ago, therefore, that is, at a time when the Khalif Omar restored the Canal, the mean level of the Red sea was 3 meters higher than at present [2].

That fresh-water Mollusca such as Aetheria and Spatha, which at present exist only in the upper Nile, were already present in this region at a time when the fauna of the Red sea lived about seven to eight meters above the present water level in the Bitter lakes, has been maintained by several observers, in particular by T. Fuchs. Very regular beds crowded with the shells of Aetheria occur, however, as was first shown by Vaillant, within the Erythraean region, above the more recent marine formations, on the Shalûf, near the Serapeum, and at a few other points to the south of Timsâh; that they should have been formed by the Fresh-water Canal alone is, as Issel has justly observed, most unlikely. We must not, however, overlook the fact that the course of the Fresh-water Canal in the valley of Gessen doubtless corresponds, up to the Seven Springs, with an ancient branch of the Nile, and there is no doubt from the observations made by members of the French expedition to Egypt at the beginning of the nineteenth century, that in 1800, before the reconstruction of the Fresh-water Canal, the Nile followed this line during an unusually high flood and reached the Seven Springs near Ismailia. The river even

[1] Renaud, Note sur la constitution géologique de l'isthme de Suez; Compt. rend., 1856, XLII, pp. 1163-1167.

[2] Lesseps, Compt. rend., 1874, p. 1743; also Laurent, Essai, p. 63. Here it is necessary to say a few words on the threshold of the Shalûf, which separates the Bitter lakes on the south from the lagoon of Suez and the Red sea. Laurent and Lesseps believed it to be a spur of the Miocene deposits of the Jebel Genéf; I could not find any indication of this, nor did T. Fuchs. In 1869 I was permitted to expose this part of the berme of the Canal by means of a small excavation, but the Canal was already in communication with the sea, in consequence of which I did not see the lower parts of Laurent's section. What I met with was blue clay rich in gypsum; above it, dipping to the north and thinning out upwards, a hard brownish-yellow bed which consists chiefly of cavernous gypsum and appeared to be the edge of a larger basin-shaped deposit of gypsum, on the surface of which, about 1·5 meters above the sea, boreholes were visible. This was again followed by blue clay and gypsum.

washed against the height of Sheich Ennedek, to the south of lake Timsâh, but flowed away northwards into lake Balâh and towards the Mediterranean [1].

From this it is clear that lake Timsâh, the lake of Crocodiles, which lies towards the middle of the isthmus, is situated within the region which is naturally inundated by the Nile.

If we now draw the conclusions suggested by these isolated data, we shall first see that all the recent marine deposits which compose the isthmus lie horizontal, that the whole of this low-lying region appears to have been formed solely by silting up, and that, at least since a certain period, the Nile has taken part in this process. Further, it is clear that the strand-line of the Red sea, when at a height of more than 60 meters, extended beyond the valley of the Nile, and the deposits of Ghizeh were then formed, which contain *Pecten erythraeus* and *Ostrea Forskali* of the Red sea—that, when at a height of 8 meters, the typical Erythraean marine fauna appeared in the Bitter lakes, but that certain extinct species of Mediterranean character and also fresh-water mussels of the Nile intermingled with it—that among the Erythraean Mollusca in the shell-beds laid dry near Suez several Mediterranean species occur at a very trifling height above the sea—finally, that in the living fauna of Suez a great number of Mediterranean Mollusca are represented by derivative forms. Thus, while the strand-line lay at a higher level, an encroachment of the Red sea into the Mediterranean region occurred; later on a temporary fusion of the faunas occurred, which, as the strand-line subsided, again became distinct. Near Suez, however, owing to this isolation, Mediterranean forms gave rise to representative species.

It is possible, and even likely, that the last movements of the strand-line took place in historic times, and we shall meet later with abundant proof of such movements in the Mediterranean within the last two thousand years. But we may regard it as certain that the Nile sent an arm through the valley of Gessen towards the Seven Springs, at a time when the Red sea lay six to eight meters above its present level and extended beyond the Bitter lakes. It is equally certain *that since then the strand-line has subsided, while the level of the Nile has not been appreciably altered.* The fall of the Nile, however, in the lower part of its course is extremely insignificant; Fraas estimates it from Assuan to Cairo at 11 centimeters and from Cairo downwards at 4 centimeters to the kilometer, or 1:9,090 and 1:25,000. The river must, therefore, be very sensitive to any alteration in the relative height of the land. A deposition of alluvium has certainly taken place, but I entirely agree

[1] The level on which are based the otherwise most valuable observations of the great scientific expedition which accompanied Napoleon I to Egypt is unfortunately quite erroneous.

with the unfavourable opinion expressed by Fraas as regards all the attempts hitherto made to obtain chronological results from the thickness of these deposits, which varies greatly according to local conditions [1].

Just as the horizontal position of all the recent marine deposits which form the isthmus reveals the fact that they were laid dry, not owing to local causes, but to some very widely extended process, so the position and past history of the Nile proves that a local elevation of the land cannot possibly have occurred in more recent times. Most observers have recognized this fact; Laurent, Vassel, and T. Fuchs have put forward the theory that it is the fresh water of the Nile which has brought about the separation of the marine faunas. Vassel and Fuchs regard the whole isthmus as formed by recent silting up [2]. 'Are we,' asks Laurent, 'to assume a slow elevation in recent times, which raised the rocky bank of the Shalûf two meters above the present level of the Red sea, or must we presuppose the simultaneous retreat of both seas [3]?' I think that the stationary state of the Nile restricts us to the latter supposition.

It is true that this refers only to the lower course of the river. According to Leith Adams fluviatile Mollusca and ancient terraces occur near Selsileh, that is, even below the cataracts, at a considerable height above the river, and further up its course such indications of higher water levels may be frequently seen; they must extend 100 to 120 feet above the river [4]. This only proves the progress of erosion, and the sinking of the river with the subsidence of the strand-line. But the age of the Nile is very great.

Traces of the fauna of the Nile are widely distributed. In the alluvial land of Ghenneh in Arabia Petraea, Bauermann found a shell of *Spatha Chaziana*, which lives at present in the Nile, and fragments of the same fresh-water mussel were found, together with stone implements, in the neighbouring turquoise mines, which are of very great antiquity [5].

Many years ago Tristan brought *Chromis nilotica*, a fish characteristic

[1] Fraas, Aus dem Orient, p. 212.

[2] T. Fuchs, Ueber die geol. Beschaffenheit der Landenge von Suez und des Amur-Liman im Nord-Japanischen Meere; Verhandl. geol. Reichsanst., 1881, pp. 178–181. The older view on the elevation of the country was represented by Ferret and Galinier, Note sur le soulèvement des côtes de la Mer Rouge et l'ancien Canal des Rois, 8vo, Paris, 1847 (from Voy. en Abyssinie).

[3] Laurent, Essai géologique, p. 17.

[4] A. Leith Adams, Notes on the Geology of a Portion of the Nile Valley, north of the Second Cataract in Nubia, taken chiefly with the View of inducing further Search for Fluviatile Shells at High Levels; Quart. Journ. Geol. Soc., 1864, XX, pp. 6–19.

[5] Bauermann, mem. cit., Quart. Journ., 1869, XXV, p. 35. The mussel evidently served as food for the labourers. These mines, situated in the Wady Maghara, which opens into the Wady Ghenneh, were discovered according to Lepsius 4,000 years B.C., and worked by a colony of labourers: Lepsius, Briefe aus Aegypten, Aethiopien und der Halbinsel des Sinai, 8vo, 1852, p. 336.

of the Nile, and other representatives of the Nile fauna from lake Tiberias, and from this he concluded that the fauna of the river must be of very great age [1]. Lortet has confirmed the occurrence of these forms; the level of the lake is, according to this observer, −212 meters; its greatest depth, situated in the north, is 250 meters, so that the bottom here attains a depth of −462 meters. Terraces which reach the level of the Mediterranean may, however, be seen around the lake, and it is quite possible that communication once existed across the plain of Jezreel [2].

*Trionyx aegyptiacus* lives in the neighbourhood of Beyrut, and it is a most remarkable fact that the crocodile of the Nile still exists in the marshy estuary of the Nahr e' Zerka, or Crocodile river, three kilometers to the north of Caesarea. Pliny knew of a town—Crocodilon—in this neighbourhood, it is mentioned by Strabo, and the ruins of a village still bear this name. Böttger has lately collected information on the subject, from which we learn that the animal is not rare, that it sometimes attacks children or sheep, and that in April, 1877, a specimen ten feet long was slain in the neighbourhood of the river [3].

These facts also throw unexpected light on the numerous and circumstantial accounts of the slaughter of a scaly monster by the knight Deodat von Gozon on the island of Rhodes in the first half of the fourteenth century [4].

[1] A. Günther, Report on a Collection of Reptiles and Fishes from Palestine, Proc. Zool. Soc., 1864, pp. 488-493; H. B. Tristram, Nat. Hist. Rev., 1865, XII, pp. 541–544, et passim.

[2] Lortet, Dragages profonds exécutés dans le lac de Tibériade (Syrie); Compt. rend., 1880, XCI, pp. 500-503. Others have assumed, on the authority of older observations made by Tristram, that the terraces on the Red sea extend to the summit of the threshold of Arabah, and that it had once discharged itself to the south (Nature, March 29, 1883, p. 520); but the exact data furnished by Lortet (e.g. Bull. soc. géol. de Fr., 1865, 2e sér., XXV, pp. 448 et seq.) do not indicate this direction, and it is very unlikely that the high threshold on the south was ever submerged, since lake Tiberias found an outlet to the Mediterranean at a lower level.

[3] O. Böttger, Die Reptilien und Amphibien von Syrien, Palästina und Cypern; Berichte Senckenberg. Naturf. Gesellsch., 1879–1880, pp. 199-206, and map of the Nahr e' Zerka, pl. iv. The 'leviathan' of Job xl and xli is certainly the crocodile, but we can hardly refer this passage to the crocodile of the Nahr e' Zerka, since the 'behemoth' mentioned at the same time is evidently the hippopotamus. Both animals have been rightly identified by S. Bochart, Hierozoicon, fol., 1563, II, pp. 753-796. On this point cf. also K. Schlottmann, Das Buch Hiob, 8vo, 1851, pp. 490-503.

[4] We possess a detailed account of this in J. Bosio, Istoria della sacra religione et Ill$^{ma}$ Militia di San Giovanni Gierosolomitano, fol., Roma, 1594, II, pp. 45-47. The incident is said to have occurred near a spring below the hill on which stands the little church of San Stefano, on the road from the town to Casali, in the time of the Grand Master Helion de Villanuova (1322-1346). Bosio's account mentions all the circumstances, both before and after the contest, which have found a place in the verses of Schiller. Apart from many absurdities in the description of the animal, we

Thus the traces of the ancient population of the Nile lie strewn over the land; this fauna is older than a large part of the adjacent Mediterranean, and older than the trough-subsidence of the Dead sea. It is possibly even of the very same age as the period of transition between the ascending to the descending series of strata near Suez.

may mention that the knight was obliged to approach it through the water, that he was forced to dismount in order to contend with it, and that the less scaly and vulnerable spot was below the neck.

# CHAPTER VI

## THE FRAGMENTS OF THE INDIAN CONTINENT

South Africa. The East Indian peninsula. Madagascar. Summary.

*South Africa.* Soundings made in the neighbourhood of Cape Colony have shown that both the east and the west coast of South Africa descend much more steeply to the depths of the sea than the south coast, off which lies the bank of Agulhas. From the Cape of Good Hope in the west and from Algoa bay in the east the hundred-fathom line departs more and more widely from the outline of the continent; it includes the bank of Agulhas, and extends about two degrees of latitude to the south of the mainland [1].

Thus the hundred-fathom line does not correspond with the truncated outline of the coast, but produces it towards the south. Further, any good geographical map will show that while the trend of the mountains in the interior is indeed clearly related to that of the coast, yet important deviations occur in this case also. From Algoa bay, or from the coast between this bay and Cape Agulhas, a series of parallel ranges runs to the west, and somewhere in the neighbourhood of Worcester, north-east of Cape Town, bends round, in accordance with the curve of the coast, to the north-north-west, or towards Namaqualand. To this series belong the Winterhoek mountains, the Lange Bergen, the Great and Little Zwartebergen, the Wittebergen, and further on the mountains of the Cold Bokkefeld, the Cedar Berge, and others. The ranges form so many ramparts around the elevated land of the interior, the Karoo; but since they run out towards the sea between Algoa bay and Cape Agulhas there is, as it were, too little of the mainland in the south-east and too much in the south-west, and there is no counterpart to the Cape of Good Hope on the east side of the continent.

This asymmetry of outline is determined by the structure of the country and is clearly expressed on the geological maps. Its essential features were correctly represented by Bain [2] many years ago, and they are still more clearly shown on Dunn's map of South Africa [3].

[1] Die Küsten- und Landes-Vermessung der Kap-Kolonie; Petermann's geogr. Mitth., 1868, pp. 23, 24, pl. iii.

[2] A. Geddes Bain, On the Geology of South Africa; Trans. Geol. Soc., 1856, 2nd ser., VII, pp. 175–192, pl. xx, xxi.

[3] E. J. Dunn, Geological Sketch Map of South Africa; from Personal Observations combined with those of A. G. Bain, Wylie, T. Bain, Atherstone, Pinchin, in Cape Colony, Sutherland in Natal, and E. Button N. of 24° lat. (fol., undated).

Between Cape Agulhas and Algoa bay the rocks of the high ranges sink beneath the sea; in Natal they partly reappear; while in the intervening district, between Great Fish river and St. John's river, chiefly in British Kaffraria, the formations of the Karoo extend from the interior to the coast, and no rampart of parallel chains bounds them on this side.

The rampart, where it does exist, consists of the most ancient rocks, while towards the interior younger formations occur and the great sandstone table-lands of the Karoo, which reach the sea in British Kaffraria, form the youngest members of this series; so that the whole land resembles a great basin, with ancient rocks forming the edge, which, however, is faulted down in an irregular manner. Towards the Cape of Good Hope the edge displays its greatest breadth; in British Kaffraria it has wholly

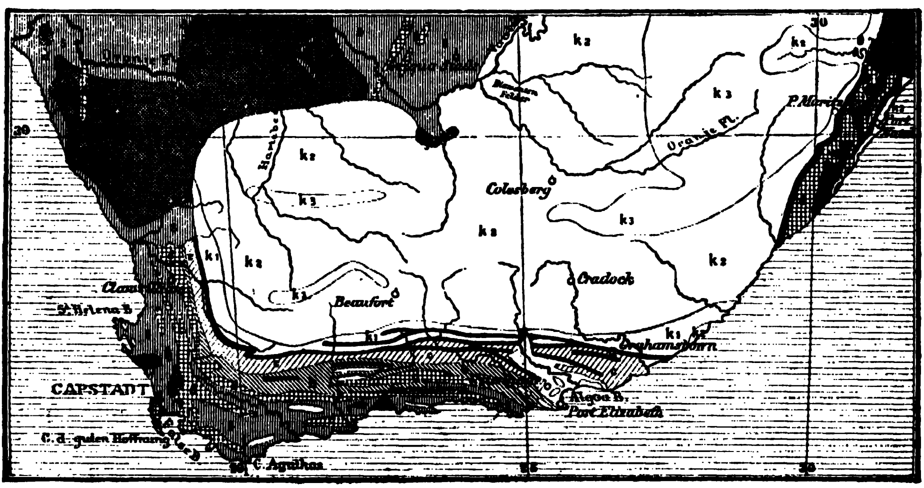



FIG. 44. *South Africa* (chiefly after Dunn).

*g*, granite and gneiss; *s*, Silurian; *d*, Devonian; *b*, bands of porphyry; *c*, Carboniferous; *black*, Dwyka conglomerate; $k_1$, $k_2$, $k_3$, Karoo sandstone and sheets of greenstone; *white*, near Algoa Bay and to the north-east of Cape Agulhas, Uitenhage formation and recent marine deposits (Tertiary or Quarternary). The patches of Cretaceous on the coast of Natal are not indicated.

disappeared. The sandstone of the Table mountain is an outlier resting unconformably on the circumvallate mountains.

Thus the asymmetry of this part of the continent, and at the same time the significance of the down-thrown areas, is apparent on the first glance at the map. 'The Table mountain sandstone,' wrote F. v. Hochstetter many years ago, 'forms to a certain extent the edge of the great continental plateau, which consists of the formations of the great Karoo, superposed one over the other in zones or in the form of a basin; this edge has sunk

along many parallel lines of fracture, and the coast-line itself perhaps indicates the outermost of these fractures [1].'

Three tectonic elements are present in South Africa.

The first of these is formed of Archaean rocks and Palaeozoic deposits which in Cape Colony have afforded marine fossils of Devonian age and Carboniferous plants; they are folded and eroded; they form the ramparts already mentioned, as well as the base of the Table mountain, and extend over wide areas in Namaqualand, Griqualand West, and the Kalahari.

The second includes the deposits of the Karoo. Their age dates from the Permian period and extends to the Trias; they are several thousand feet thick, lie horizontally on the ancient folded formations, and have never yet furnished any trace of marine organisms.

The third element consists of younger marine deposits of the Mesozoic period; they have never been observed on the table mountains of the interior or indeed at any great distance from the existing sea-coast; they have but little influence on the configuration of the continent, and will be discussed later.

The most important part in the interior of the country is taken by the second element, the deposits of the Karoo. In the whole of Cape Colony and in Natal, as for example near Pietermaritzburg, they commence with an accumulation (sometimes very thick) of great boulders of different kinds of rock. That these were transported by ice was first asserted by Sutherland, who compared them with the Permian ice-drift of England [2]. The series is known as the *Dwyka conglomerate*, and forms a part of the lowest group, distinguished by Bain as the Ecca beds. Above it lie the *lower Karoo* or *Koonap* sandstones or shales, which at Klein-Roggeveld and other places contain numerous fossil trees. Then follow the widely extended *upper Karoo sandstones* or *Beaufort beds*; besides *Glossopteris Browniana* and perhaps *Phyllotheca indica*, they contain here and there the remains of Palaeoniscus and above all of Dicynodon, Oudenodon, Galeosaurus, Micropholis, and other strange reptiles. This division is overlaid by the *Stormberg beds*—white and yellowish sandstones, with grey and reddish beds of shale, frequently coal-bearing. These beds also contain reptiles, but Dicynodon appears to be absent; and they are probably the source from which the remains of *Tritylodon longaevus* [once regarded as] a mammal, found near Thabachou, Basutoland, are derived [3].

[1] F. v. Hochstetter, Beiträge zur Geologie des Caplandes; Reise der österr. Fregatte Novara, Geologie, Theil II, 4to, Wien, 1866, p. 28.

[2] Sutherland, Notes on an Ancient Boulder-Clay of Natal; Quart. Journ. Geol. Soc., 1870, XXVI, pp. 514–516. The whole series of the Karoo beds is given in great detail by Rupert Jones and Tate, after Bain, op. cit., 1867, XXIII, pp. 142–149, and according to Wylie, tom. cit., pp. 171–173.

[3] R. Owen, On the Skull and Dentition of a Triassic Mammal (*Tritylodon longaevus*, Ow.) from South Africa; Quart. Journ. Geol. Soc., 1884, XL, Discuss., p. 152.

These horizontally stratified masses of sandstone contain numerous sheets of volcanic rocks, which are variously described as porphyritic amygdaloid, melaphyre, trap, basalt, or greenstone; they have recently been made the subject of numerous petrographical investigations, and appear to be of very diversified character. They often give rise to obvious ledges on the slopes of the table mountains, and frequently cover their highest parts like a roof. Thus, according to Stow, a fragment of one of these sheets forms the great cliff beneath the summit of the Hangklip, which rises above the surrounding country to the south of the Stormbergen [1], and another produces the crest of a large part of that stupendous precipice in which the Quathlamba (Drakensberg) terminate in the east towards Natal, and even their highest part, the Mont-aux-Sources (said to be 10,000 feet high), consists, according to Griesbach, of the edge of one of these covering sheets [2].

The contrast between the flat-lying masses of the Karoo from the Dwyka conglomerate to the Stormberg beds, and the folded complex on which they rest, is as a rule clear enough: a more obscure problem, however, and one not yet completely solved, arises from a study of existing descriptions. Both on Table mountain itself, and far away from it in Natal, transgressive or apparently transgressive masses of sandstone occur immediately over the folded formations. These are older than the sandstones of the Karoo, and perhaps indicate a transgression which preceded the Dwyka conglomerate; they are called by Griesbach and others the *Table mountain sandstone.*—

The folds of the older formations, which in the south of the continent assume, as we have seen, the form of ramparts surrounding the great plateau of Karoo sandstones, strike at first, west of Algoa bay, from east-south-east to west-north-west, then further on from east to west, corresponding to the course of the mountain crests; the southern edge of the sandstone region also runs approximately in the same direction [3]. From Cape Town onwards these older formations follow the west coast to the north, and in Namaqualand gneiss forms the greater part of the surface, overlaid, however, in places by isolated outliers of the horizontally stratified Table mountain sandstone [4]. This extensive gneiss region is followed on the east by a Palaeozoic area which comprises the western half of Griqualand West. The structure of this, in spite of the complete absence of fossils,

[1] G. W. Stow, On some Points of South African Geology; Quart. Journ. Geol. Soc., 1871, XXVII, pp. 497–548, in particular p. 531.

[2] C. L. Griesbach, On the Geology of Natal; tom. cit., 1871, XXVII, pp. 53–72, pl. ii, iii.

[3] R. Pinchin, A Short Description of the Geology of Part of the Eastern Province of the Cape of Good Hope; op. cit., 1875, XXXI, pp. 106–108, pl. iv.

[4] Rubridge, On some Points in the Geology of South Africa; op. cit., 1859, XV, pp. 195–198.

has been worked out by Stow, at least as regards its main features. Anderson's map of the desert of Kalahari shows the northern continuation of the stratified systems distinguished by Stow [1].

In order to follow these important investigations let us start from a point easily found on the map, the confluence of the Vaal with the Orange river. From this point an important escarpment extends to the north-east, running at first parallel to the Vaal, and then following the course of the Haart river; it marks the boundary between the Palaeozoic formations and the horizontal deposits on the east. Although known as the Campbell range, it is not a mountain chain, but the edge of an extensive plain or of a somewhat convex or buckler-shaped surface, and is formed by the outcrop of a very thick bed of siliceous limestone; at its foot there appear here and there the remains of a still older and steeply up-tilted series of strata.

Starting from Campbelltown let us now ascend the face of the Campbell range and cross the broad limestone region to Griquatown. Here the limestone comes to an end, and is succeeded by the long shoulders of the Griquatown (Kuruman) range which strike to the north-north-east. These consist of siliceous schists, carrying magnetic iron ore, and in the south asbestos; it is this chain which is broken through by the Orange river in the sharp bend it makes to the south near Prieska. The Griquatown range extends to the north far beyond Griqualand; in the south, on the other side of the Orange river, it is continued in the Doornbergen, which runs to the south-east; this mountainous zone is known for a distance of more than two degrees of latitude.

It is succeeded on the west, near Moss Fontein and Ongeluk, by a region of felspathic rocks and amygdaloids, of considerable extent and often covered by red sand. Still further to the west we reach the long ridges of the Matsap and Klipfontein mountains, which are composed of ancient folded quartzite and run north-north-east parallel to the Griquatown range. These are only the foot-hills of the Langeberg, that remarkable chain which is crossed by the Orange river between Bulfontein and Kheis; approaching from the south it runs at first parallel to the above-mentioned ridges to the north-north-east, but further to the north follows the direction of the meridian, and according to Anderson's map even extends along the eastern part of the desert of Kalahari, nearly as far as latitude 22°. Thus the length of the Langeberg would amount to about seven degrees of latitude. This remarkable chain consists as far as

[1] G. W. Stow, Geological Notes upon Griqualand West, op. cit., 1874, XXX, pp. 581–682, pl. xxxv–xxxix; also E. Cohen, letter in the Neues Jahrb. für Min., 1873, pp. 52–56, and A. A. Anderson, Notes on the Geography of South Central Africa, in Explanation of a New Map of the Region; Proc. Roy. Geogr. Soc., 1884, VI, pp. 19–36, and map.

it has been explored, like those just mentioned, of folded or steeply upturned quartzite which Stow assigns, but only conjecturally, to the Devonian. Now we reach the projecting arms of the sandy desert, and near Kheis schistose rocks, the relations of which to the gneiss of Namaqualand are only imperfectly known.

From the foregoing we perceive that in the centre of the continent is a vast folded region of Palaeozoic rocks striking to the north or north-north-east, which was either exposed by the denudation of the Karoo beds, or, as Stow thinks, served from the beginning as the boundary of these deposits. The desert of Kalahari appears to belong wholly, or at least for the greater part, to this Palaeozoic region.

Having established these facts let us turn to the horizontally stratified region of the Karoo.

The course of its continuous southern border is indicated on Fig. 44 by the outcrop of the Dwyka conglomerate; above it rises the lower, and then the upper or Beaufort sandstone, which forms the surface of the land far and wide. In the west the Stormberg beds occur upon it only as isolated outliers, while in the east they form a continuous sheet.

The southern margin of the great sandstone region extends in Cape Colony through Kliprug Kop near Calvinia, Schoorstein Berg, Schildpad Kop, Spitzkop, and many others; the Great Winterberg belongs to this region. The Dwyka conglomerate reaches the sea near the mouth of the Great Fish river and emerges from it again near St. John's river to the north of Kaffraria. Between these two points, as we have already seen, the great mass of sandstone also reaches the sea.

The eastern border of the sandstone mass is very sharply defined and runs through Natal, Zululand, and the eastern Transvaal into the immediate neighbourhood of the Olifant river; and it may be followed from 31° 30′ to about 24° 15′, that is, through more than seven degrees of latitude. From west to east the table-land ascends, and then suddenly sinks in the direction of Natal. We have already mentioned that the Quathlamba or Drakensberg form the eastern edge of the table-land, that they attain their greatest height in the Mont-aux-Sources, about 10,000 feet high, and that intercalated effusive sheets form both this edge and the peaks which rise from it.

For a closer study of this important line we shall now follow the descriptions of Griesbach [1] in the case of Natal, and those of Cohen [2] for the district between Lydenburg and Delagoa bay.

[1] C. L. Griesbach, Geologischer Durchschnitt durch Südafrika, Jahrb. geol. Reichsanst., 1870, XX, pp. 501-504, pl. xix, and in greater detail in the passage mentioned, Quart. Journ. Geol. Soc., 1875, XXXI.

[2] E. Cohen, Erläuternde Bemerkungen zu der Routenkarte einer Reise von Lydenburg nach den Goldfeldern und von Lydenburg nach Delagoa Bay, 8vo, 1875.

We must first observe that the line is not straight; near the sources of the Tugela a great excision occurs which displaces the crest towards the west, although further north it again assumes nearly the same direction as in Natal. Still further north it terminates near the Olifant river, and while the plateau of Lydenburg attains a height of some 1,800–1,900 meters, and many of the hills upon it rise to over 2,000 meters, the Mauch Berg even to 2,660 meters, the Olifant flows far below at a level of 600 meters.

Notwithstanding its sinuosities, the eastern border of the sandstone region is determined, in Natal and Zululand, probably indeed for its whole length, by a very great fault, as has been well recognized by Rehmann[1]. This seems to me proved by the fact that, on the east coast of Natal, and in other localities more to the north, sunken fragments of Dwyka conglomerate and Karoo sandstones may be observed at a very low level. This also explains the fact that, as shown in Fig. 44, the zone of the Dwyka conglomerate is repeated on the east in Natal.

Let us examine a transverse section of the chain of Quathlamba and its foreland in Natal.

From the Mont-aux-Sources the land descends, according to Griesbach, in great terraces, which correspond to the basset edges of the Karoo beds and the ends of the intercalated igneous sheets. Near Pietermaritzburg we reach some shaly layers which are peculiar to the lower horizons. They pass downwards fairly gradually into the Dwyka conglomerate, which borders the foot of the great escarpment. This conglomerate rests unconformably on an older quartzite which is still, however, horizontally stratified. It is regarded with much reason as the equivalent of the Table mountain sandstone of the Cape of Good Hope. Below the Quathlamba it forms several typical table mountains, as for instance the Krantzkop on the Tugela. Beneath the quartzite the rivers have in many places exposed ancient folded schists and gneiss. The gneiss forms the foundation of the whole series. Before we reach the sea on the east the Dwyka conglomerate reappears, and is followed on the coast by isolated outliers of Karoo sandstone, the beds of which dip towards the sea. The cliff on which the lighthouse of Durban Harbour is built is composed of the seaward-dipping beds of such an outlier, the continuation of which is to be sought far above in the pile of strata which crop out in the face of the Quathlamba.

From the foregoing we see that the Karoo deposits once extended much further to the east, and that the outliers on the sea-coast are thrown down

[1] A. Rehmann, Das Transvaal-Gebiet des südlichen Africa in physisch-geographischer Beziehung, Mitth. geogr. Ges. Wien, 1883, XXVI, pp. 257–266, 321–362, 369–395, 417–443, map and 2 plates; also F. Jeppe, Die transvaal'sche oder südafrikanische Republik, Peterm. geogr. Mitth., Ergänzungsheft, XXIV, 1878, with the map by Jeppe and Merensky; further, Jeppe, Notes on some of the Physical and Geological Features of the Transvaal, Journ. Roy. Geogr. Soc., 1877, XLVII, pp. 217–250, and map.

along one or more great faults; the existing slopes of the Quathlamba do not, however, coincide with the line of faulting. The great fracture that severed that part of the continent now lying beneath the sea took place much nearer the existing coast-line; subsequent denudation has diminished the steepness of its face and caused its edge to retreat gradually inland. The resulting scarp is the scarp of the Quathlamba; the head waters of the Tugela are still active in driving it back, and similar forces are at work along the whole line. High though the Mont-aux-Sources rises at present above the lighthouse of Durban, yet the original face of the fault must have looked down upon the sea with an altitude greater still.

The same general features reappear on the slope of the Quathlamba in the north. In order to observe them let us accompany Cohen on his journey from Lydenburg to Delagoa bay.

As soon as we reach the margin of the plateau to the east of Spitzkop, we notice a change in the character of the landscape. The steep cliffs and gorges of the table-lands give place to dome-like hills and rounded valleys; this is the granite region, which descends in several steep steps to the east. Still further to the east, in the Umswasi mountains, near the river Ingwanya we again meet, for the first time since leaving the high mountains, with stratified rocks, such as quartz sandstone and friable black shales, both of which closely resemble the rocks of the great plateau. The long chain of the Lembobo mountains, which follows on the east, is composed of felsite porphyry.

It is quite possible that the stratified rocks of the Umswasi mountains correspond to the down-thrown outliers on the coast of Natal. Isolated sandstone mountains in the midst of the plain were met with by Machado to the east of the Lembobo chain, i.e. on its seaward side [1].

While the Karoo beds are thus sharply bounded on the southern and eastern side, their area becomes constricted to the north, and the western margin is much broken up by denudation. A description of the irregularities of the western border is not, however, a part of my scheme. We have already seen how the Palaeozoic rocks in Griqualand advance from the west towards the eastern border of the Campbell range (Kaap Plateau of Jeppe). The Karoo beds which rest in a horizontal position against this border consist of friable shales, but here also the remains of Dicynodon are known [2]; within this region lie the most valuable diamond mines, which extend into the Orange River Colony. The mines are worked in a vertical direction in great pipes or necks filled with a mass of tuff, charged with foreign fragments, and in this the diamonds occur. According to Chaper's description, this diamond-bearing mass was formed by eruptions in a pasty

[1] J. J. Machado, Caminho de ferro de Lourenço Marques á fronteira de Transvaal; Bol. Soc. Geogr. Lisbon, 1880, 2ª ser., pp. 67–104, in particular p. 89.

[2] Lee, Geol. Mag., 1879, 2nd ser., VI, p. 192.

condition or incompletely molten state; Cohen compares them to the Maare of the Eifel[1].

The Palaeozoic deposits probably extend without interruption from the Campbell range to the west of the Haart river along the western border of the Hohe Feld into the district between the Marico and the upper Limpopo; there, according to Hübner's observations[2], the granite comes out from beneath them on the Kornkoppe south of the confluence of these two great rivers. Great sheets of greenstone form the surface of the ground, both in the south on the Pilandsberge towards Rustenburg, and towards the north-west in the neighbourhood of Shoshong. The Archaean formations, however, play a most prominent part in the structure of the extensive heights between the Limpopo in the north and the Buschfeld and Olifant river in the south. The eastern part in particular, called by Rehmann the Ingalale plateau, which extends as far as the great bend described by the Limpopo, seems to consist of a great core of granite surrounded by a mantle of schists. These schists, according to Rehmann, also form the Lechlaba mountains, which, although they lie very nearly on the prolongation of the great line of the Quathlamba, must yet be regarded as parts of an independent mountain system.

Outliers of sandstone do not reappear until we reach the northern border of the Ingalale plateau in the Zoutpansberg, towards the valley of the Limpopo, and here they must be included in the Karoo series.

On the other side of the Limpopo the structure of the country appears to remain the same as far as the Zambesi. Granite and crystalline schist everywhere crop out; they include the gold-bearing district of Tabi, and only here and there are covered by outliers of sandstone, which are probably the denuded remains of the transgressive deposits of the Karoo. Apart from the patch occurring on the river Serorume in lat. 23½° S., which is probably connected with the greenstone sheet of Shoshong, Hübner encountered to the south of Inyati, in lat. 20° S., horizontal beds of sandstone containing some fossil wood, and probably belonging to the Karoo sandstones. Near the Kraal Malisa, in lat. 19° 50′ S., a similar horizontal outlier of sandstone occurs on the upper Guay; this contains intercalated sheets of greenstone.

Still further to the north extensive deposits of sandstone with accompanying coal-beds occur on the Zambesi; these were first observed by Livingstone and Thornton, and subsequently described in detail by Kuss. They lie below the waterfalls from about 16° 40′ to 15° 50′; to the south

[1] E. J. Dunn, On the Mode of Occurrence of Diamonds in S. Africa, Quart. Journ. Geol. Soc., 1874, XXX, pp. 54–60; M. Chaper, Note sur la région diamantifère de l'Afrique australe, 8vo, Paris, 1880, in particular p. 42 et seq.; E. Cohen, Ueber die südafrikanischen Diamantfelder, 8vo, 1883, p. 5 (from the V. Jahresber. des Vereins für Erdkunde zu Metz für 1882).

[2] A. Hübner, Geographische Skizzen aus Südost-Afrika; Petermann's geogr. Mitth., 1872, XVIII, pp. 422–431, pl. xxi.

of them, Kuss observed a large development of Archaean rocks, and in many places some brown porphyry. In the Lupata mountains, which are cut through by the Zambesi, this overlies red sandstone; a large outlier of sandstone also occurs further to the south near Senna [1].

Thomson has shown that in the north, from about lat. 12° to 10° S., a large flat-bedded plateau of sandstone reaches the sea; this has been denuded by the river Ruvuma and so divided into two parts, Mavia and Makonde. In the east along the coast the height of the sandstone plateau only amounts to a few hundred feet; it extends in the form of a wedge up the river Ruvuma to about lat. 39° E., and attains on its inland side an altitude of more than 2,500 feet. This vast table-land rests on granite, and its exposed foundation, like the granite region of Dar-Fur and Kordofan, is covered towards the interior with steep and isolated mountains. In a restricted area, however, between Itule and Kwamakanja on the Lujende, which flows from the south into the Ruvuma, a mass of coal-bearing shale belonging to the sandstone series has been thrown down in a trough-fault, and has thus, according to Thomson, been preserved from destruction in the midst of the granite [2].

Thus we approach the region lying between latitude 10° and 5° S., where the same explorer has collected so much instructive information, and within which two great sandstone areas, an eastern and a western, may be distinguished [3].

The eastern area lies near the coast, does not rise to peaks of any considerable eminence, and is bounded towards the interior by a high cliff, which marks the commencement of the Archaean region. The cliff retreats furthest from the coast in about latitude 8° S., reaching almost to longitude 36° E., and thus the sandstone here attains its greatest breadth; towards the north it becomes more and more restricted, and opposite Pemba island is merely a narrow band. The sandstone is accompanied by coal; limestone beds also appear, and Thomson mentions fossils of the Carboniferous period from two localities in the north of this area.

The lofty Archaean table-land extends as far as lakes Tanganyika and Nyassa, and far beyond the latter to the west. But in Ujiji and Ukaranga, on the north-east side of lake Tanganyika, and at some places on the west side and at the southern end of the lake, the western area of sandstone begins, and is continued for an unknown distance towards the upper Congo.

[1] Livingstone and Thornton, Account in the Journ. Geogr. Soc., 1861, XXI, pp. 261, 291, et passim; H. Kuss, Note sur la constitution géologique d'une partie de la Zambésie, Bull. soc. géol. de Fr., 1884, 3e sér., XII, pp. 303–317 and geological map.

[2] J. Thomson, Notes on the Basin of the River Rovuma, East Africa; Proc. Roy. Geogr. Soc., 1882, new ser., IV, pp. 65–79 and map.

[3] By the same, To the Central African Lakes and Back, 8vo, 1881, Appendix III; Notes on the Geology of East Central Africa, Vol. II, pp. 299–307 and geol. map.

This sandstone is of great thickness and has on the whole retained its horizontal position, although on lake Tanganyika it is traversed by faults.

Although the synchronism of these sandstones with those of the Karoo has not been proved, yet the essential elements which enter into the structure of the country, the Archaean foundation, associated with older folded schists, and horizontal transgressive plateaux of sandstone, are extremely similar to those of the south.

Let us cast a hasty glance at the two lakes. Nyassa is surrounded on the north by an older volcanic region, surmounted by recent eruptive cones. Tanganyika is let down into the horizontally stratified sandstone and its foundation of Archaean rocks. Its southern half, from about latitude 7° 8′ to 8° 30′ S., crosses an extensive region of ancient eruptive rocks. Since the time that our knowledge of this lake has made some approach to exactness it has been regarded as a down-thrown area. Stanley even believed that the northern half was of more recent origin than the south, and that alterations in the discharge of the Lukuga bore witness to this fact. Thomson also recognizes it as a sunken area. The precipitous descent of the sandstone to the lake and the manner in which the latter cuts across the eruptive mass about its southern half are adduced in support of this view, and probably with reason [1].

Indeed I do not see in what way these two great depressions, each of which, although of very trifling breadth, is prolonged through about five degrees of latitude, could have been produced unless by trough-faults, and in my opinion their mode of origin was similar to that of the Red sea, the Dead sea, and the Shotts.

The structure of the west of Africa is even less completely known to us than that of the east. The map constructed by Lenz shows, however, how widely distributed the most ancient rocks are in this region

[1] H. M. Stanley, Through the Dark Continent (German edition by Böttger), 8vo, 1878, II, p. 37: 'Kirungwé Point consists of perpendicular walls—from 50 to 200 feet high above the lake—of a fine reddish sandstone with horizontal strata. Their peculiar appearance may be imagined when the boat's crew cried out:—"Oh, mother, this is a fort! See, there are the windows and here is one of the gates." Kirungwé Point appears to be a lofty swelling ridge, cut straight through to an unknown depth. As may be seen from a glance at the sketch of the "High Place of the Spirit Mtombwa," on the opposite side of the lake, there seems ground for believing that this ridge was once a prolongation of the plateau of Marungu, as the rocks are of the same material, and both sides of the lake show similar results of a sudden subsidence without disturbance of the strata.' Also J. Thomson, On the Geographical Evolution of the Tanganyika Basin; Rep. Brit. Ass., Southampton, 1882, pp. 622, 623. Here we may recall the striking marine forms among the Mollusca of Tanganyika and the occurrence of the Cretaceous genus Pyrgulifera in this lake: Tausch, Ueber einige Conchylien aus dem Tanganyika-See und deren fossile Verwandte, Anzeig. Akad. Wiss. Wien, 1884, p. 130. Near the north-west side of Nyassa, on the Archaean plateau, Drummond has lately found deposits, apparently of lacustrine origin, with fishes, Mollusca, and leaves: Nature, April 10, 1884, p. 551.

also [1]. The conglomerate rocks of Pungo Andongo (lat. 9° 24′ S.) in eastern Angola, and the horizontal plant-bearing sandstones on which they rest, strongly reminded Livingstone of the sandstones of the east. It is very probable that similar conditions prevailed over the whole breadth of the continent.—

We have thus been able to distinguish in Cape Colony, and thence to the north of the Transvaal, an older group of folded rocks and a younger transgressive group of flat-lying beds, composed chiefly of sandstone, and corresponding in age with the Permian and Trias. These are the deposits of the Karoo. In certain localities one of the latest stages of the Carboniferous system appears to take part in the horizontal transgression. Further to the north we have again found older folded rocks and outliers of transgressive horizontal sandstone, but we have no direct proof that the latter is of the same age as the sandstones of the Karoo. Nevertheless there plainly exist two elements very similar to one another, and standing in the same tectonic relation to each other, which, according to the present state of observation, compose the interior of the continent from the Cape to below latitude 6° or 5° S.

There is yet a third tectonic element in South Africa, which however, as we have already said, has only exerted a subordinate influence on the structure of the great continent, and is so far only known in the neighbourhood of the sea-coast; this consists of the marine deposits of the second half of the Mesozoic period. However insignificant these isolated patches may be in extent, yet the interest which attaches to them in the geological history of Africa is by no means trifling. They lie at great distances from one another and are of different age, but everywhere contain marine fossils. They are without exception more recent than the sandstone masses of the Karoo, and indeed than all the transgressive sandstones of the interior, in which no trace of marine animals has as yet been found. In certain cases even it is clear that some of the dislocations which have determined the existing form of South Africa date from the earlier part of the Mesozoic period.

The first group of these patches occurs on the west coast in two widely separated regions; it is of Cretaceous age, and was first made known by Giebel, Lenz, and Szajnocha [2]. The first region lies to the north of the Equator; on the *Elobi islands* in Corisco bay, which only rise 8–10 meters above the sea, horizontal beds of sandstone are met with which have afforded a large number of Ammonites; the sandstone is continued on to

[1] O. Lenz, Geol. Karte von West-Afrika; Petermann's geogr. Mitth., 1882, pl. i.

[2] Giebel, Zeitschr. für die ges. Naturw., 1876, XLVIII, p. 58; Lenz, Geol. Mitth. aus West-Afrika, Verh. geol. Reichsanst., 1878, p. 148; L. Szajnocha, Zur Kenntniss der mittelcretacischen Cephalopoden-Fauna auf den Inseln Elobi in West-Afrika, Denkschr. Akad. Wiss. Wien, 1884.

the mainland. *Schloenbachia inflata* occurs here, and, according to Szajnocha, that variety of it which predominates in the Ootatoor group of the Cretaceous system in India. The second region lies more than 15 degrees of latitude further to the south on *Fish bay*, south of Mossamedes. In this locality richly fossiliferous beds were observed many years ago by Lieutenant Wolf, to the north of the Pillar of Bartolomeu Diaz [1]. *Schloenbachia inflata* is placed by German geologists in the Gault, in France it is assigned to the lower Cenomanian.

The next group of these patches lies in the south and south-eastern part of Cape Colony. It falls into two series, a Mesozoic and an upper Tertiary or Quaternary.

The Mesozoic deposits bear the name of the *Uitenhage series*, are horizontally stratified, and consist of more or less glauconitic beds of sandstone and shale; some of the beds contain plant remains, cycads, and ferns, which differ from those of the Karoo sandstones; other beds contain marine shells, which for a long time were considered to be of Jurassic age [2]; but, according to the later investigations of Holub and Neumayr, there is increasing evidence to show that they belong to the Neocomian [3]. These remarkable deposits, in which the alternation of beds containing terrestrial plants with those containing marine shells reveals clearly enough the proximity of some shore line, occur chiefly in the valleys of the rivers which flow into Algoa bay and the neighbouring bay of St. Francis. They rest immediately upon the Palaeozoic deposits of the mountain ranges which surround the Karoo sandstone, extend up the valley of the Sunday river to the foot of this sandstone, and also appear further to the west in some smaller patches still lying on the Palaeozoic. From this it is clear that the denudation of the Palaeozoic formations in South Africa was accomplished before the time of the lower Cretaceous [4].

The deposits of the upper Tertiary or Quaternary period also occur

[1] (Lieut. Wolf), Narrative of a Voyage to explore the shores of Africa, Arabia, and Madagascar, performed in H.M. Ships *Leven* and *Barracouta* (directed by Capt. W. F. W. Owen), 8vo, Lond., 1833, II, p. 231; fossils in sandstone to the north of the Pillar of Bartol. Diaz in lat. 11° 53′ 3″ E., long. 15° 40′ 7″ S., between Port Alexander and Little Fish bay; also Journ. Geogr. Soc., 1833, III, p. 217.

[2] Stow, mem. cit., Quart. Journ. Geol. Soc., 1871, XXVII, p. 497 et seq. For the fauna and flora in particular see Kraus, Ueber die geol. Verhältnisse der östlichen Küste des Kaplandes, Amtl. Bericht üb. d. XX. Versamml. d. Gesellsch. deutsch. Naturforsch. u. Aerzte, Mainz, 1842; and Ralph Tate, On some secondary Fossils from South Africa, Quart. Journ. Geol. Soc., 1867, XXIII, pp. 139–175, pl. v–ix.

[3] E. Holub and M. Neumayr, Ueber einige Fossilien aus der Uitenhage-Formation in Süd-Afrika; Denkschr. Akad. Wiss. Wien, 1881, XLIV, pp. 267–276, 2 plates.

[4] Stow has also sent Mollusca of the Uitenhage series to England, which are said to come from the Zambesi (loc. cit., p. 505, note); Herr Holub, however, assures me that these specimens were brought by dealers, and that this statement as to the place at which they were found is of no value.

chiefly in the neighbourhood of Algoa bay; they lie partly on the Uitenhage and partly on the Palaeozoic beds. Isolated patches of this kind are also said to rest on the ancient rocks near Bredasdorp, to the north of Cape Agulhas.—

The third group of these patches appears on the coast of *Natal* and of *Zululand*. We have seen that in the west of Natal the precipitous edge of the horizontally stratified Karoo forms the declivity of the Quathlamba, while towards the east, on the seashore, down-thrown outliers of the same Karoo sandstones occur, dipping towards the sea. On the sea-coast there now appear, from the southern end of Natal to the bay of St. Lucia, isolated exposures of marine deposits belonging to the middle and lower Cretaceous, which have been described by Garden, Baily, and Griesbach [1]. They rest with horizontal stratification, and therefore unconformably, on the inclined beds of the down-thrown Karoo sandstones, and thus show that the great dislocation, the eroded border of which is represented by the Quathlamba, is older than the Cenomanian stage. The Cretaceous formation here presents, in a clearly expressed manner, those characters which we shall meet with again on the east coast of India.

The fourth locality in which marine Mesozoic deposits are known lies further to the north, near *Mombasa*, on the coast of Suaheli. The first indication of their existence, an Ammonite sent by Krapf to O. Fraas, from Kisaludini, near Mombasa, suggested the upper horizon of the Callovian; but a larger series of Ammonites, collected by Hildebrand's negroes and examined by Beyrich, represents a higher zone of the Jurassic, the Kimmeridge, and this in the same stage of development as in India, where it is known under the name of 'Katrol sandstone [2].'

Thus we have on the west coast the zone of *Schloenbachia inflata*; in the south the Uitenhage series, which we place on the horizon of the Neocomian; in Natal and Zululand Cenomanian and upper Cretaceous; and on the coast of Suaheli the upper stages of the Jurassic. Up to the present marine beds of this kind have nowhere been found in the interior of the country, not even in those parts of the south which are best known. The Archaean and Palaeozoic, together with the broad patches of Karoo deposits which rest upon them, form the lofty plateaux of the interior, which have not, at least as far as we can judge, been reached by these Mesozoic marine deposits. The significance of the latter in the history

[1] R. J. Garden, Notice of some Cretaceous Rocks near Natal, South Africa, Quart. Journ. Geol. Soc., 1855, XI, p. 453, and W. Baily, Description of some Cretaceous Fossils from South Africa, tom. cit., pp. 454-465, pl. xi-xiii; Griesbach, op. cit., 1871, XXVII, pp. 60-70, pl. iii. The first find was made by Fynn in 1824. On the river Umtata, further to the south, the fossil remains of tortoises are said to occur.

[2] O. Fraas, Württemb. Jahreshefte, 1859, XV, p. 356; E. Beyrich, Ueber jurassische Ammoniten von Mombassa, Monatsber. Akad. Berlin, 8. März 1877, pp. 96-103.

of the Indian Ocean only becomes clear from a comparison with India. This we will now attempt to make.

*The Indian Peninsula.* India is divided into two parts by the broad alluvial regions of the Indus and the Ganges; the more northerly of these parts comprises the mountain chains, and when we speak of the *Indian peninsula* we refer only to the southern part. This division, which is marked in strong relief on the surface of the planet, corresponds in the west, towards the Indus and north of Delhi, with a fundamental difference in the structure and composition of the two parts of the country—a contrast which is precisely similar to that between the Alps and their foreland. Here the peninsula is the foreland. Strange to say, however, the contrast is not so marked in the north-east; we shall see that the same elements which compose the peninsula are continued into Assam, south of the Brahmaputra, far to the east-north-east, and that even the overthrust outer border of the high mountain chains presents in some places a resemblance to the peninsula, if not in structure, yet at least in the stratified sequence.

The Geological Survey of India, on which a number of the most distinguished specialists are engaged, has already made such progress that the chief structural features of the country may be clearly perceived. The study of the voluminous Reports of the Survey has been greatly facilitated by the general summary of their contents, published by Medlicott and Blanford in 1879[1], and most happily supplemented by Waagen's treatise on the distribution of the organic remains[2]. To these works, and the publications of the Geological Survey subsequent to 1879, we are indebted for the following facts.

Although mountains of considerable height occur in the peninsula, yet, with the exception of the extremely ancient Arávalli mountains in the north-west, there is not a single chain the direction of which is determined by the strike of the rocks. All is table-land, either fractured or worn by erosion. The Sahyádri or western Ghâts, the Sátpura mountains on the south of the Narbada, like the Vindhya on the north, are only the borders of great plateaux. The highest summits of the Nilgiri, which rise in the air to over 8,000 feet, are fragments of the

[1] H. B. Medlicott and W. T. Blanford, A Manual of the Geology of India, 8vo, Calcutta, 1879, 2 vols., and map. In consideration of the extreme difficulty of attempting a uniform orthography in a work like the present, I have adopted, in the case of India, the spelling of the Geological Survey; in treating of the north I found this led to fresh difficulties, especially as regards the sibilants; in this case I have followed Richthofen's method (China, I, pp. xxi and 170, note), but it was impossible to avoid inconsistencies. The decimal system could not always be used in cases where a round number of English or Russian feet was frequently mentioned.

[2] W. Waagen, Ueber die geographische Vertheilung der fossilen Organismen in Indien; Denkschr. Akad. Wiss. Wien, 1878, XXXIX b, pp. 1-21, and map.

same table-land; the highest peak of the southern Sátpura, Pachmarhi, 4,380 feet high, consists of horizontal beds of sandstone, and the loftiest summit of the northern Sahyádri, Mahábleshwar, 4,540 feet, is a fragment of a horizontal sheet of basalt.

Several distinct elements enter into the structure of the peninsula. The first of these comprises *Archaean formations*, consisting chiefly of gneiss, with which is associated a great series of very ancient schists, including that group of ancient masses of quartzite and schist named by the Indian geologists the 'Transition' or 'Sub-metamorphic rocks,' which in their tectonic relations are also closely connected with the Archaean. The *Vindhyan group* forms the second element; a series of strata of sandstone, shale, and limestone, undoubtedly of detrital origin, which probably correspond in age to a large part of the Palaeozoic aera, but which, strange to say, have as yet furnished no trace of organic remains, although in the high mountains of the north Palaeozoic fossils are not wanting. The Vindhyan are followed by the *Gondwána group*. These are sandstones containing remains of plants and reptiles, and sometimes coal-bearing; the lower stages are the equivalents of the African Karoo, the upper extend beyond the period of the Karoo into that of the plant-bearing deposits of Uitenhage, and like these include towards the sea-coast intercalated marine beds. The sub-littoral deposits of South Africa are repeated in India with slight but peculiar modifications. Finally, another independent element extending over a wide area is formed by a very great accumulation of eruptive flows and ashes, which are usually designated by the general name of '*Deccan trap*.'

The Archaean formations, exposed by denudation, occupy a considerable part of the surface of the peninsula. They consist chiefly of gneiss, which forms the island of Ceylon, Cape Comorin, and the western Gháts as far as latitude 16°; it is exposed, except for comparatively short intervals, over the whole east coast of the peninsula, as far as the bend described by the Ganges. This mass of gneiss thus extends from Point de Galle through about 19 degrees of latitude towards the north. It includes the whole of southern India and the whole of Mysore, sinks to the west beneath the Deccan trap and the stratified rocks, and is continued into Assam on the other side of the Ganges.

To this great dominant mass of Archaean rocks two smaller ones must be added. The first, of an irregular semicircular form, is situated in Bundelkhand; its north-western end lies in the neighbourhood of Gwalior. The second, distributed in long folds and ridges, forms the Arávalli mountains on the north-western border of the peninsula.

The Arávalli present us with one of the most ancient folded ranges to be seen anywhere on the globe. Their central and eastern parts, between latitude 24° and 29° N., a distance of more than 500 kilometers, have

been described in detail by Hacket[1]. The chain runs to N. 36° E. along the eastern edge of the desert of Rájputána, and is resolved towards the north into isolated ridges which a little further on sink into low hills amidst the desert; its last spurs reach the town of Delhi. Gneiss and ancient schists and quartzites are the sole constituents of these folded chains, the extreme antiquity of which is apparent from the fact that in some localities horizontal beds of the Vindhyan group rest upon them unconformably. Towards the south-east an extremely long fault running parallel with the strike cuts off the Arávalli from a broad plateau of horizontal Vindhyan beds. This long fault follows the course of the river Chambal in a more or less northerly direction, and is doubtless prolonged as far as the Jumna above Agra.

That the strike of these primaeval folds is completely independent of the trend of the existing great mountain ranges of India is a point which may be emphasized in passing.—

The Vindhyan beds, wherever they have been met with in the north of the peninsula, lie fairly flat, just as they do in the neighbourhood of the Arávalli hills.

Far to the north, on both sides of the river Chenáb, rise the isolated Korána mountains, with steep ridges striking north-east to south-west; they are composed of rocks which resemble the ancient quartzites and schists of the Arávalli, and attain a maximum height of 957 feet above the plain. This little group is of great importance in connexion with the remarks which are to follow, since it approaches to within 65 kilometers of the outer border of the great folded mountains.—

To the north of Madras the eastern Gháts stretch along the sea-coast towards the lower course of the Kistna; they consist of Archaean rocks, and are here termed the Gháts of Nellore or the *Yellakonda mountains*. This great ridge, as King and Foote have shown, is bounded on the west by a fault, along which a great mass of Vindhyan rocks has been thrown down. The sunken area has the form of a crescent; its northern end lies almost in latitude 17° N., still to the north of the Kistna; its southern end, in about 13° 20′, north-west of Madras. The western is more strongly curved than the eastern boundary, which corresponds to the fault of the Yellakonda. The downthrown mass, as shown by the intense folding and overthrusting, is a fragment of a great and ancient mountain chain, which, however, is younger than the chain of the Arávalli, since the Vindhyan beds are involved in the folding. The folding took place from east to west[2].

[1] C. A. Hacket, On the Geology of the Arvali Region, Central and Eastern; Rec. Geol. Surv. Ind., 1881, XIV, pp. 279-303, and map.

[2] W. King, jun., On the Kadapah and Karnúl Formations in the Madras Presidency, Mem. Geol. Surv. Ind., 1872, VIII, in particular pp. 259-265; R. B. Foote, Sketch of the

This folded fragment, to which the wild quartzite scenery of the Nágari and Tirupatti mountains near Madras belongs, is, in spite of its great antiquity, the most recent indication of extensive tangential movement on the whole peninsula; for southern India, like southern Africa, has not been subjected to any extensive folding, at least since the Carboniferous period. So much the greater in extent and importance are the subsidences and faults. These disturbances also affect a part of the superposed plant-bearing Gondwána strata, the several subdivisions of which we will now consider.

The series of Gondwána deposits begins with the *Tálchir stage*, composed of extremely fine-grained silt-like shales and soft sandstones, in association with beds of boulders; these vary in size from small pebbles to blocks weighing 30 tons. The great blocks sometimes lie in the very finest silt; Blanford, Oldham, and Fedden have expressed the belief that they owe their transportation to ice [1]. The resemblance to the Dwyka conglomerate, which forms the lowest division of the African Karoo series, is very striking. Following Feistmantel's classification, which is based on the examination of the plant remains, we also assign to this lowest division the coal-bearing stage of Karharbári. Gangamopteris is of frequent occurrence in these lower deposits, and Glossopteris is richly represented [2].

The next member consists of the plant- and coal-bearing *Damúda stage*, in the highest subdivision of which, the Mángli shales, a typical Labyrinthodont, *Brachyops laticeps*, has been found.

The third is the *Panchét stage*, which has furnished the remains of Dicynodon in addition to Labyrinthodon. With this stage the lower Gondwána terminates.

These three chief stages correspond, as is indicated by many identical species of plants and the genus Dicynodon, to the Dwyka conglomerate and probably to the whole of the lower Karoo, the Beaufort and the Stormberg stage in South Africa. No trace of marine animals has ever been found in them. There are many reasons for regarding them as synchronous with the whole period comprised between the Rothliegende and the close of the Trias or thereabouts.

Generally speaking, then, we correlate the lower Gondwána with the Karoo; in the *upper Gondwána* we meet with several characters which indicate a more recent age, although the genus Glossopteris, for example, from the lower Gondwána is also found here.

Work of the Geological Survey in Southern India, from the Journ. of the Madras Lit. Soc., 1882, 50 pp., 8vo, in particular p. 18.

[1] W. T. Blanford, Description of the Geology of Nágpúr, Mem. Geol. Surv. Ind., 1872, IX, p. 324, Oldham's note in this; F. Fedden, On the Evidences of 'Ground-Ice' in Tropical India during the Tálchír Period, Rec. Geol. Surv. Ind., 1875, VIII, pp. 16–18.

[2] O. Feistmantel, A Sketch of the History of the Fossils of the Indian Gondwána System; Journ. Asiat. Soc. Bengal, 1881, L, pp. 168–219.

In the lowest stage of the upper Gondwána we meet with genera such as Sphenopteris, Thinnfeldia, Taeniopteris, besides a large number of Cycads, Palissya, Cunninghamites, &c. In the somewhat higher deposits of the Kota and Maleri stage are found the remains of true crocodiles such as Parasuchus, and fishes such as Dapedius, Lepidotus, Tetragonolepis, which we are accustomed in Europe to find chiefly in the Lias. In conclusion there follows a long series of still higher plant-bearing strata, and the uppermost of these, the Umia beds, alternate, in the sub-littoral region, with marine strata, which, as we shall see directly, are the equivalents of the Uitenhage series of Cape Colony.

In South Africa we have seen the thick deposits of the Karoo resting horizontally on an older foundation; they form the table mountains in the interior of the country, and the great escarpment of the Quathlamba. No younger strata rest upon them. At a lower level, at their foot as it were, lie much younger plant-bearing beds with the intercalated marine deposits of Uitenhage. The discordance is complete.

The same discordance prevails between the lower and upper Gondwána in India. In addition to the difference in age between Uitenhage (Neocomian ?) and upper Gondwána (Lias ?) there exists, however, the following distinction between the two regions. The great patches of the lower Gondwána do not form here, as in Africa, a lofty continuous table-land; India has been profoundly affected by erosion, and the most important visible fragments of the lower Gondwána owe their preservation chiefly to the fact that they are let down into the mass of gneiss, between trough-faults which existed before the deposition of the upper Gondwána. The great denudation took place after these movements and before or during the deposition of a part of the upper Gondwána, so that a transgression of the latter may be seen in very many places. Nor are the Gondwána deposits confined to the sub-littoral region; they extend on the contrary into the interior of the country.

The coal-bearing deposits of the lower Gondwána thus recall in their mode of distribution the patches and strips of Carboniferous and Trias faulted down into the Archaean mass of central France, of which the great trough-subsidence between Creusot and Montchanin furnishes so instructive an example. For a long time the most experienced mining engineers in Europe refused to believe in the original continuity of such widely separated patches and in the existence of such stupendous faults, of which there is often no indication whatever at the surface of the ground. The long bands of in-faulted beds were regarded as local formations deposited in separate valleys and bays; and much actual proof by means of boring and mining was necessary to carry conviction to the contrary. The more worthy of note is the fact that Blanford, with keen perception had discovered the true interpretation in India many years ago.

The most important exposures of the lower Gondwána group, excluding those in Assam and Sikkim, are as follows: first a long series of wedge-shaped or irregularly elongated downthrown areas and bands, which begins in the east near Ràniganj, north-west of Calcutta, at the edge of the gneiss where it meets the alluvial land of the Ganges; at first this follows approximately the course of the river Damúda, it then proceeds south of Hazáribágh through Chutiá Nágpur, and is continued to the west by the vast coal region of south Rewa, which may be followed further in a west-south-westerly direction towards Jabalpur, close to the northern edge of the great eastern arm of the Deccan trap.

Proceeding from Jabalpur in the same direction towards the west-south-west we reach, concealed at first for a short distance by the Deccan trap, the great coal-field of Sátpura, which extending still to west-south-west, south of the Narbada, finally disappears beneath the trap. Thus this series forms a long, more or less continuous, curve running across the greater part of the peninsula, from the middle course of the Narbada to the alluvial plains of the lower Ganges.

A second series of great patches extends from Chutiá Nágpur to the south-east, includes there the coal-field of Tálchir, and reaches the eastern edge of the gneiss near Cuttack and the estuaries of the Mahánadi.

A third series, in which we may perhaps include the area of Ellichpur, in the middle of the trap region, emerges from beneath the eastern edge of the trap, strikes to the south-east fairly parallel to the preceding series, follows for a long distance the course of the Godávari, and reaches the edge of the gneiss near Rájáhmahendri.

Let us select a few of these areas as examples, beginning with Ràniganj, at the eastern extremity of the first series. It was here that Blanford recognized, many years ago, the importance of the faults. He showed that this coal-field, apart from other dislocations, is cut off on the south by a powerful fault, with a downthrow of certainly not less than 9,000 and probably of more than 12,000 feet. The older beds on the northern side of the basin rest on the gneiss and dip to the south; the more recent beds succeed them in the same direction, and the whole of this great series of strata ends abruptly along the southern fault [1].

The small but important coal-field of Karharbárí, in the vicinity of Hazáribágh, is bounded, according to Hughes, both on the north and south by faults running from east to west. It is thus a true trough, although the throw of the faults is inconsiderable [2]. Generally speaking it appears

[1] W. T. Blanford, On the Geological Structure and Relations of the Ràniganj Coal-field, Bengal; Mem. Geol. Surv. Ind., 1861, III, in particular pp. 149–153.

[2] T. W. H. Hughes, The Kuhurbari Coal-field; op. cit., 1871, VII, in particular p. 222 et seq.

that along the river Damúda, as at Ráníganj, the downthrow of the larger patches is always to the south.

The south Rewa region, which extends from the river Son for more than 300 kilometers to the south, is still little known. Its eastern prolongation, between the rivers Rer and Kanhar, points to its connexion with the series of outliers of the Damúda, and is, according to Griesbach, a true trough formed between two almost parallel faults in the north and south [1]. In its western part, near the Son, the northern edge of this great basin is rectilinear, directed to the east-south-east and determined most probably by a fault; here the upper Gondwána deposits extend transgressively on to the older formations [2].

The Sátpura region, exclusive of smaller patches of the Gondwána which crop out on the edge of the great Deccan trap, is about 180 kilometers long; it lies to the south of the Narbada and fairly parallel to this river. The beds of the lower Gondwána group are here, as in the west of the south Rewa basin, inclined to the north, and the northern edge is most likely a fault; the upper Gondwána beds, however, lie transgressively over those parts of the supposed line of fault which have so far been examined, whence it follows that here also the great subsidence took place before the deposition of at least a part of the upper Gondwána [3].

It is not my intention to multiply examples; those already cited are sufficient to show the importance of the linear fractures, which affected the great mass of the Indian peninsula after the period of the lower Gondwána and before the deposition of a part of the upper Gondwána [4].

Let us now leave the coal-bearing regions of the interior, and turn our attention to the sub-littoral zone of the east, which has furnished many contributions towards a knowledge of the physical history of the peninsula.

Among the most remarkable results of the geological exploration of the Indian peninsula is the proof that the eastern margin of the great region of gneiss has formed a natural limit to deposition ever since the middle of the Tertiary period. The lower horizons of the plant-bearing beds, downthrown remnants of which, preserved from denudation, we have just traced in the interior of the country, are, so far as our knowledge extends, wholly absent from the outer border, with the exception of a few small patches in the extreme north: the series begins with the Rájmahál group, which

[1] Griesbach, Geologyof the Ramkola and Tatapani Coal-fields; op. cit., 1880, XV, p. 141.

[2] Medlicott and Blanford, Manual, I, p. 201; also Hughes, Notes on the South Rewa Gondwána Basin, Rec. Geol. Surv. Ind., 1881, XIV, pp. 126-138.

[3] Manual, I, pp. 215, 216.

[4] In the Tálchir area on the Bráhmani, north-west of Kuttack, the north side is faulted, and there is a general dip of the strata to the north, while the great Godávari series, bounded by straight parallel lines and intersected by faults within them, is yet represented as a deposit between originally parallel rectilinear shores: W. King, The Geology of the Pránhita-Godávari Valley, Mem. Geol. Surv. Ind., 1881, XVIII, p. 169.

corresponds to the base of the upper Gondwána. The upper plant-bearing beds are accompanied here and there by marine sediments, which is never the case in the interior; finally, they are sometimes covered by still younger marine deposits; these also do not extend into the interior of the country.

On the narrow plain which lies at the foot of the western Ghâts, no Mesozoic deposits are to be seen; only near Quilon and to the south of this town there appears a variegated sandstone of post-Tertiary age; in the east it is called the Cuddalore sandstone. Another patch of it may be seen near Nagarcoil, about 20 kilometers north of Cape Comorin [1]. We will now pass to the east coast, not forgetting to remark that Mesozoic deposits have not yet been met with in Ceylon.

Not far north of Trichinopoli, in about latitude 11° N., the first deposits of the Rájmahál appear, on the eastern edge of the gneiss. Upon them or immediately on the gneiss rest marine Cretaceous beds, which extend nearly as far as Pondicherri, perhaps even as far as Sripurmatúr, near Madras. They gave the first impulse to Stoliczka's comprehensive investigations [2], from which we learn that the Cenomanian, Turonian, and Senonian of Europe are here represented in three distinct stages, with a fauna which differs in several essential respects from the Cretaceous fauna of Europe and North Africa, but at the same time presents a striking resemblance to that of Natal [3]. On the Cretaceous lie patches of the Cuddalore sandstone.

The patches of Rájmahál beds extend northwards along the edge of the gneiss and are widely extended near Madras beneath the recent alluvium. Near Sripermatúr badly preserved Ammonites appear with other fossils, which Stoliczka held to be upper Jurassic, but which Waagen identifies as Neocomian [4].

Traces of the Rájmahál beds extend still further, past Nellore and Guntúr [5], until, between the rivers Kistna and Godávari, there becomes visible above them a more complete series of strata, which have been

[1] W. King, General Sketch of the Geology of the Travancore State, Rec. Geol. Surv. Ind., 1882, XV, pp. 87-93; and by the same, The Warkilli Beds and reported associated Deposits at Quilon, tom. cit., pp. 93-102, map. I have passed over in silence the older statements of Cullen on the presence of marine fossils in limestone near Quilon, in consequence of the doubts which they have raised.

[2] H. F. Blanford, On the Cretaceous and other Rocks of the South Arcot and Trichinopoli Districts, Madras, Mem. Geol. Surv. Ind., 1865, IV, pp. 1-217, map; F. Stoliczka, Cretaceous Fauna of Southern India (Palaeontol. Ind.), 1865-1871.

[3] Medlicott and Blanford; Manual, I, p. 292.

[4] R. B. Foote, On the Geology of parts of the Madras and North Arcot Districts lying north of the Palar River, Mem. Geol. Surv. Ind., 1873, X, pp. 63-124; W. Waagen, Jurassic Fauna of Kutch (Palaeont. Ind.), I, p. 236; and by the same, Geogr. Verbr. foss. Org., p. 12.

[5] R. B. Foote, On the Geological Structure of the Eastern Coast from lat. 15° northward to Masulipatam; op. cit., 1880, XVI, pp. 49-84, map.

described in a most instructive manner by W. King, and to which we now turn our attention [1].

The mighty Godávari flows through the gneiss in a deep ravine and emerges from it near Rájáhmahendri in latitude 17° N., where its great delta begins. To the west of the river the elongated Godávari coal-field, distinguished by its rectilinear and parallel boundary lines, extends to the south-east and reaches the eastern edge of the gneiss; it is formed of the lower divisions of the Gondwána group; and extending *transversely across its extremity* lie in complete discordance the Rájmahál beds of the upper Gondwána, which follow the course of the coast-line and the edge of the gneiss. Here there can be no doubt that the edge of the gneiss was formed after those Gondwána beds which are faulted down in the coal-field, and before the Rájmahál beds which follow the sub-littoral zone.

In the lowest beds, which lie on the edge of the gneiss and across the coal-field, only the Rájmahál flora has been found. Above them follow shales with a slightly different flora and badly preserved marine fossils, as near Sripermatúr, and then finally sandstone in which, besides many other less distinctive marine Mollusca, *Trigonia ventricosa* and *Trigonia Smeei* appear. The former is a characteristic fossil of the Uitenhage; this furnishes a new and important link with South Africa. The Cretaceous deposits of Trichinopoli are not known in this locality; on the other hand a fragment of a basaltic sheet appears near Rájáhmahendri in intimate association with richly fossiliferous marine deposits of lower Tertiary or upper Cretaceous age; its extrusion therefore doubtless occurred within that long period during which the far-distant mass of the Deccan flows was built up.

On the basalt rests the Cuddalore sandstone.—

The next great patch is situated on the border of the gneiss near Cuttack, where the Mahánadi emerges from the primitive rocks in about 20° 30′; in this exposure only the plant-beds of the Rájmahál are known to occur [2].

The coast here leaves the edge of the gneiss, and the latter is continued inland towards the great bend of the Ganges. From the river Mor in latitude 24° N. up to the Ganges in 25° 20′ the edge of the gneiss is bordered by plant-bearing beds, and these, with intercalations of older basaltic flows, form the Rájmahál mountains, of which we have already made frequent mention. The gneiss reaches the Ganges near Colgong: its eastern edge, as shown by Ball's observations, is determined by

[1] W. King, The Upper Gondwánas and other Formations of the Coastal Region of the Godávari District; tom. cit., 1880, XVI, pp. 195-264, and map.

[2] V. Ball, On the 'Atgarh Sandstones,' near Cuttack, Rec. Geol. Surv. Ind., 1877, X, pp. 63-68, map; and O. Feistmantel, On some Fossil Plants from the Atgarh Sandstones, tom. cit., pp. 68-70.

faults. First appear small patches of beds belonging to the Tálchir group; then, extending transgressively over a part of the latter, the Damúda beds, which like the Tálchirs also belong to the lower Gondwána; and finally, covering a large area, the Rájmahál beds, to which belong the basaltic sheets and dykes of this region. This northern part of the edge of the gneiss is thus distinguished from the southern part by the presence of small remnants of lower Gondwána, by ancient flows of basalt, and by the absence of marine beds. The conclusions to which Blanford was led by an examination of the Ràniganj coal region have been confirmed by Ball: it thus appears that the basaltic eruptions in Bengal are not only later than the lower Gondwána, but also posterior to the great faults of this region, that the plant-bearing Rájmahál beds have hardly been disturbed since the time of their first deposition, that faults in these beds are of very rare occurrence, and, finally, that the lava flows to the south of the bend of the Ganges probably mark the conclusion of a great period of disturbance[1].

Having followed the beds resting against the gneiss from Trichinopoli to the Ganges, i.e. from latitude 11° to 25° 20′ N., let us now turn our attention for a moment to the mountains of Assam, which lie beyond the basin of the Ganges, outside the peninsula in the restricted sense of the word.

Just as the Rájmahál mountains rise within the sharp bend of the Ganges, so a mountain range rises within the elbow of the Brahmaputra to the east of the alluvial plain, and there are certain circumstances which lead us to regard this range as a continuation of that on the Ganges, notwithstanding the great distance which separates them. On the maps the range on the Brahmaputra is named, after the tribes which inhabit it, the Gáro, Khasia, Jaintia, and Mikir mountains; its length amounts to more than 400 kilometers and most of its summits rise to between 4,000 and 6,000 feet. Its northern border follows the south bank of the Brahmaputra, while its sharply defined southern border describes an arc, the successive directions of which are, in the west near the Brahmaputra to the south-east, somewhat further on from west to east, and finally to north-east. We will call this range the mountains of Assam, or, following Medlicott, the *Shillong plateau*.

This mountain segment occupies a very peculiar position. To the north of it rise the inverted folds of the outer border of the Himálaya; on the south it is approached by the folded outer border of the Barail and Pátkoi chains, forming part of the great Burman chain, which extends from this point towards Arakan, Cape Negrais, and even much further to the south. It rises aloft between these two great regions of folding, which converge towards one another in the valley of the Brahmaputra, and its north-eastern

[1] V. Ball, Geology of the Rajmehal Hills; Mem. Geol. Surv. Ind., 1877, XIII, pp. 155–248, map, in particular p. 221.

end disappears near Golághát (in about longitude 91° E.) beneath the alluvial plain of the great river.

We are indebted to Medlicott and Godwin-Austen for the most important contributions to our knowledge of its structure [1].

The northern flank which looks towards the Brahmaputra has a gentle slope and is formed solely of gneiss and granite. It reaches the river in many places, and several hills, which rise from the alluvial land to the north, show that the same Archaean rocks proceed almost up to the outer border of the Himálaya [2]. This gneiss is precisely similar to that which forms so large a part of the peninsula. It rises towards the south, and there supports rocks which are probably a continuation of the Vindhyan of Behar (south of Patna). To the south a steep fault occurs in the neighbourhood of Shillong, accompanied by a vast mass of basaltic lava flows, which are perhaps a continuation of the ancient basalts of Rájmahál.

Above all these rocks, gneiss, Vindhyan and basalt, a series of much more recent fossiliferous beds extends over the summit of the south side of the table-land in horizontal transgression. This consists first of Cretaceous beds similar to those of Trichinopoli and Natal, then of Nummulitic limestone, and, as it would appear from several indications, some patches of upper Tertiary marine deposits. The character of the Cretaceous beds is such as to suggest that the northern shore of the Cretaceous sea once extended across this table-land.

All these horizontal transgressive strata are bent in a great flexure over the abrupt southern edge of the plateau, and then dip steeply downwards. To the south of the flexure some upturned and intensely folded fragments of the recent Tertiary beds are visible.—

The west coast of the Indian peninsula differs essentially from the east. From Cape Comorin to beyond Bombay it is formed by the Sahyádri or western Gháts, that is to say, by the edge of the table-land, and, with the exception of the post-Tertiary Cuddalore sandstone near Quilon, in the extreme south, no marine deposit rests against this great scarp. The

[1] T. Oldham, On the Geological Structure of a Portion of the Khasi Hills, Bengal, Mem. Geol. Surv. Ind., 1858, I, pp. 99-210, map; H. B. Medlicott, The Coal of Assam, op. cit., 1865, IV, pp. 387-442, and Geological Sketch of the Shillong Plateau in NE. Bengal, op. cit., 1871, VII, pp. 151-207, map, in particular general section on p. 154; further, Rec. Geol. Surv. Ind., 1874, VII, p. 61; H. H. Godwin-Austen, Notes to accompany a Geological Map of a Portion of the Khasi Hills near long. 91° E., Journ. Asiat. Soc. Beng., 1869, XXXVIII, part 2, pp. 1-27, map, and Notes on the Geology and Physical Features of the Jaintia Hills, tom. cit., pp. 151-156; Medlicott and Blanford, Manual, II, pp. 682-703; T. D. La Touche, The Daranggiri Coal-field, Garo Hills, Assam, Rec. Geol. Surv. Ind., 1882, XV, pp. 175-178, map.

[2] Mallet observed one of these bosses of hornblende schist on the left shore of the Raidak river in 87°47′ E., only a few hundred yards from the upturned Tertiary deposits of the foot-hills of the Himálaya: On the Geology and Mineral Resources of the Darjiling District and the Western Duars, Mem. Geol. Surv. Ind., 1875, XI, p. 44.

watershed of the peninsula for the whole of its long course lies always near the coast, so that the rivers all discharge to the east, and only in the south does a transverse depression of any importance extend into the interior. Notwithstanding this continuity the scarp consists of two quite distinct parts. From Cape Comorin in latitude 8° N., northwards to latitude 16° N., it is formed by the great gneiss region of the east; and from there to the gulf of Cambay, beyond latitude 20° N., by the vast accumulation of the lavas and ashes of the Deccan.

Eight degrees of latitude on the west coast thus belong to the gneiss, and four to the lavas; the age of the latter corresponds approximately to the interval between the Cretaceous and Eocene, and probably extends also into the latter period [1]. The coast-line proceeds, continuously and without any change of direction, from one region to the other. It does not, however, form the western boundary of the lavas; they are spread far and wide through Káthiáwár, and their last outliers extend even into the folded mountains of Sind. To the north and east the great mass breaks up into table-lands and outlying hills; we have already met with fragments of this kind on the east coast even near Rájáhmahendri. It is consequently not easy to estimate even approximately the original extent of the flows: but to give some idea of it, Indian geologists point to the fact that the railway from Bombay to Nágpur, which is 825 kilometers long, does not leave the volcanic rocks until close to Nágpur, and that the lavas must be regarded as having originally extended through nearly 10 degrees of latitude and 16 degrees of longitude [2].

The volcanic masses attain their greatest thickness near Bombay. The principal mass affords indications of land and fresh-water formations only; it was certainly not formed beneath the sea. Only its most remote outliers, in Sind and on the east coast, are associated with marine deposits. The cavity created by such discharges of lava as these must have been immense.

Where the gulf of Cambay separates the chief mass of the lavas of the Deccan from the plateau of Káthiáwár, marine transgressions begin to manifest themselves, partly beneath the edges of the lavas, partly above them. The first transgression observed here belongs to the Cenomanian stage. This appears in the north-east of the bay, near Baroda, crops out from beneath the western edge of the lavas, near Bágh, and may be traced into the interior, up the lower valley of the Narbada to the district south of Indore. Its deposits are known as the 'Bágh beds [3].'

[1] Neumayr, Die Intertrappean Beds im Dekkan und die Laramiegruppe im westlichen Nordamerika, Neu. Jahrb. f. Min. 1884, pp. 75, 76; Duncan in Medlicott, Ann. Rep. for 1883, Rec. Geol. Surv. Ind., 1884, XVII, p. 7.

[2] Medlicott and Blanford, Manual, p. 300.

[3] W. T. Blanford, On the Geology of the Taptee and Lower Nerbudda Valleys; Mem. Geol. Surv. Ind., 1869, VI, pp. 163-384, map, pl. i.

The Cenomanian beds of Bágh do not contain the same fauna as those of Natal, Pondicherri, and Assam, but rather that of the Cenomanian beds of Ras Fartak in Arabia, of Egypt and the Mediterranean region. From this fact we may draw two conclusions. First, that since the Cretaceous type of Natal and of the east coast of India is repeated much further to the east, as for instance in Japan [1], there must have existed at the time of the middle Cretaceous a separation between two distinct marine areas, one of which extended from the south of Europe across North Africa and Arabia to beyond the gulf of Cambay; the other, also of great extent, was bounded in this direction by the south-east coast of Africa, the east coast of India, and the mountains of Assam. Further, it follows that each of these great seas enlarged its bounds by transgression during the Cenomanian period.

With the Cretaceous a series of partly marine and partly fluviatile Tertiary deposits appears for the first time on the gulf of Cambay; these are more recent than the lavas. They do not extend so far eastwards into the interior of the country as the Cretaceous beds of Bágh, but they stretch far to the north-west, and are indeed only the outliers of those extensive Tertiary formations which compose a large part of the folded chains of Sind. They commence between the lower Tápti and lower Narbada with Nummulitic limestone of lower Tertiary age, which is followed by middle Tertiary beds with Balanus; on the little island of Perim in the gulf of Cambay sandstone occurs with the remains of Mastodon, Dinotherium, Brahmatherium, and other representatives of a great terrestrial fauna, which has ten species in common with the Sivalik fauna of the foot-hills of the Himálaya.

The lower members of this Tertiary series border the basaltic plateau of Káthiáwár on its south side, are continued thence to Cutch, and westwards across the Indus into the great mountain chains of Sind.

Just as the whole series of strata, from the Cenomanian stage upwards, which extend from the mountains of Burma, overlap the ancient gneiss and Vindhyan beds of the mountains of Assam, so all the strata, from the Cenomanian stage upwards, which extend from the folded mountains of Sind, encroach upon the outer borders of the ancient rocks of the peninsula, as far as the Narbada and the lower course of the Tápti.

In Cutch however, nearer to the outer border of the chains of Sind, marine deposits of Jurassic age appear beneath the outliers of the volcanic

[1] E. Naumann, Ueber das Vorkommen der Kreideformation auf der Insel Yezo (Hokkaido), 8vo, Yokohama, 1880; Mittheil. d. deutsch. Gesellsch. f. Natur- und Völkerkunde Ostasiens, Part XXI, 19 pp.—Szajnocha's observation that *Schloenbachia inflata* from the equatorial west coast of Africa occurs as a variety in the Cretaceous of Pondicherri is at present too isolated to permit of any conclusion as to the western extension of this sea.

sheets. They rise like islands from the alluvial land and are thrown into several folds[1]. The folding begins simultaneously with the increased development of marine sediments. The oldest visible beds belong to the period of the Great Oolite. Their fauna, and in part even the lithological character of their oolitic rocks, are of European type. It is a very remarkable fact and—in its bearing on the question of the limits of formations—instructive in the highest degree, that a whole series of secondary zones in the middle and upper Jurassic have been observed here by Stoliczka and Waagen, which present the same characteristic species, succeeding one another in the same order as in central Europe. One of these, the zone of *Peltoceras acanthicum*, or the Katrol sandstone, we have already mentioned as occurring at Mombasa in East Africa. The series seems to be continued with little interruption up into the Tithonian. Above the obviously Jurassic zones, beds containing some species of the fauna of Uitenhage occur; and above these others containing a number of species of the Aptian of France[2].

The Jurassic deposits of Cutch proceed to the north along the outer border of the spurs of the Arávalli mountains, beneath the plain of Rájputána, and are known even to the west of Jesalmer. With them we enter a region which is distinguished from the peninsula both by folding and by the development of the marine deposits, an intermediate area, as it were, between the peninsula and the high mountains. But the remains of terrestrial plants, intercalated at various horizons with the marine beds, point to the fact that the coast was not far distant.—

*Madagascar*. Of late years the works of Grandidier and of the English missionaries have greatly increased our knowledge of the structure of Madagascar. The following main features may be recognized[3]:—

[1] A. B. Wynne, Memoir on the Geology of Kutch, Mem. Geol. Surv. Ind., 1872, pp. 1–293, map; Waagen, Jurassic Fauna of Kutch, I, 1875 (Palaeont. Ind.), Introduction and pp. 224–238.

[2] The succession of the European horizons observed in Cutch is as follows: Putchum group = Great Oolite (below, Trigonia, Corbula, and others; above, *Oppelia serrigera*); Zone of *Stephanoceras macrocephalum*, of *Perisphinctes anceps*, of *Peltoceras athleta*, of *Amaltheus Lamberti*, and of *Ammonites cordatus*, of *Peltoceras transversarium*, of *P. acanthicum* (Katrol sandstone = Mombasa in East Africa); on this lies the lower part of the Umia group with species of the Tithonian and the Portland beds (Waagen, p. 234). Then follows a great thickness of plant-bearing beds. The Umia horizon presents points of resemblance with the African deposits of Uitenhage; *Trigonia ventricosa* of Uitenhage, which appears with *T. Smeei* on the east coast, occurs here, and *T. Smeei* also appears fairly high up in the plant-bearing beds (Manual, p. 259). These are covered in one locality by Aptian beds. This is in complete accordance with what has been said in an earlier passage as regards the age of the Uitenhage beds.

[3] A. Grandidier, Madagascar, Bull. soc. géogr., Paris, 1871, 6e sér., I, pp. 81–108, map; 1872, 6e sér., III, pp. 369–371; La province d'Imerina, op. cit., 1883, 7e sér., IV, pp. 242–249, and map, and in many other places; J. Mullens, On the Central Provinces of Madagascar, Proc. Geogr. Soc., London, 1875, XIX, pp. 182–205, and Journ. Geogr. Soc.,

The central part of this great island, from its northern extremity down to about latitude 22° S., is a great mountain mass of granite and gneiss, which comprises in particular the two provinces of Imérina and Betsiléo. Its height is about 1,500 meters. It is bounded on the east and west by abrupt scarps, on the south by a transverse chain; in Imérina its breadth is about 130 kilometers, more to the south near Sirabé 90 to 100 kilometers, and only 56 kilometers in latitude 22°, where both sides of the mass are visible from the top of Mount Kirianga, and its southern termination is not far off. The watershed lies quite close to the eastern border.

Travelling from the east coast towards Antanánarivo we find the face of the scarp divided into three steps or terraces; these are united in the north, and at the place of union, in 17° 20′–17° 40′, lies the great lake Alaotra at an altitude of 900 meters. The inner step is the most important, and is continued to the south. Along the scarp rise enormous isolated table mountains, which form strong natural fortresses, and have played an important part in the history of the island; such, for example, are the fortified mountain Isahazávona on the boundary of the well-wooded province Tanála, which lies at the foot of the slope, and the famous Ikongo, 8 kilometers in length, which rises 300–500 meters above the plain, bearing on its broad summit five towns and two rivers. The Záfirambo maintained it successfully against the Hóvas in two great sieges. To the south of the Ikongo, near the head waters of the river Mátitánana, the eastern side descends in a single step to a depth of over 800 meters, and near the south-eastern corner rises the high solitary granite mountain of Ivohibé.

In the north, within the bay of Bombatoke, the western side is divided into four steps and is therefore easier to surmount than the eastern side, which runs for long stretches in a continuous wall; nevertheless the Hóva fort—Antóngodrahója—in latitude 17° S., rises to a height of 1,500 meters on the edge of the western side. In latitude 18° 40′ this side also becomes a single cliff, which is more than 800 meters high. In the south the principal western step bears the name of Bóngo Lava.

The rivers of the central highland descend in great waterfalls over the steps. The surface is very uneven, great granite shoulders rise above it; the valleys, and particularly the broad plains between the steps on the east, are covered with a thick layer of red clay, in which the water cuts deep furrows. In Bára, in the south-west, the granite, according to Cohen, forms the foundation of a desert tract; this is followed to the west by a broad depression with terraced sides, the bottom of a dried-up lake, and beyond

1875, XLV, pp. 128–152, map; Recent Journeys in Madagascar, op. cit., 1877, XLVII, pp. 47–72, maps; W. Deans Cowen, Geographical Excursions in South Central Madagascar, Proc. Geogr. Soc., 1882, new series, IV, pp. 521–537, map; J. Sibree, The great African Island, Chapters on Madagascar, 8vo, London, 1880.

it, in about latitude 22° 10′–22° 25′ S., rise the group of Isálo mountains, a range of sandstone table mountains, deeply eroded by water-courses[1].

The highland also bears volcanic mountains. To the south-west of Antanánarivo rise the group of *Ankaratra*, composed of five volcanic cones; these are the highest mountains of Madagascar, and the loftiest of them reaches, according to Johnson, a height of 2,873 meters. To the north-west of these, on lake Itasy, comes an extensive volcanic district comparable with the Phlegraean fields; Mullens counted here forty craters. Many others are scattered over western Imérina, and the eruptive region seems to be continued towards the north in this sporadic fashion as far as the great volcanic table mountain Vóambóhitra, which stands at the north-west edge of the highland, and thence to the Radama islands, to the mighty volcano Katowla, within the bay of Passandaya, to Mount Amber at the northern end of the island, and then to Mayotta, Johanna, and the Comoro islands[2].

The highland slopes down to the north and its rocks reappear in the off-lying islands. Herland's description of *Nossi-Bé* furnishes a good example. The southern promontory of the island Lugubé is formed, like the island of Nossi-Komba, of granite and ancient schists. The northern part, on the other hand, consists of ancient sandstone, of a red and yellow colour. The whole centre of the island is volcanic and contains several craters and seven crater lakes[3]. On the east coast of Nossi-Bé lies a fragment of Nummulitic limestone. This probably marks the commencement of that broad band of Mesozoic and Eocene deposits which surround the granitic highland of Madagascar to the west and south as far as Fort Dauphin in the south-south-east, and which Grandidier believes to be the relics of a once much more extensive sheet. The Eocene deposits have afforded Nummulites, Alveolina, *Velates Schmideliana*, and others; the Mesozoic beds appear to be rich in fossils, particularly near the river Onilahy, which flows into the bay of St. Augustin[4].

[1] Cowen, loc. cit., p. 530. Fossils are said to be contained in the sandstone, but unfortunately no further details are known. Sibree (loc. cit., p. 34) describes stratified yellow sandstone on the river Betsiboka; Buckland many years ago mentioned the 'New Red Sandstone' of Port Louquez in the north of the island: Trans. Geol. Soc., V, p. 478.

[2] On the north-east coast also Coignet only found granite and basalt, and an insignificant patch of a more recent deposit, possibly of Tertiary age: F. Coignet, Excursion sur la côte nord-est de l'île de Madagascar, Bull. Soc. Géogr., Paris, 1867, 5e sér., XIV, in particular p. 279 et seq.

[3] F. Herland, Essai sur la topographie de Nossi-Bé, sur sa constitution géologique, &c., Revue Coloniale, avril 1856, 25 pp. and geological map of Nossi-Bé and Nossi-Kuma; cf. also Ann. d. Mines, 1856, 5e sér., VIII. The sandstone of Nossi-Bé is probably the same as that on the north-west coast, described by Guillemin as coal-bearing: E. Guillemin, Note sur une exploration géologique à Madagascar pend. l'ann. 1863, Ann. d. Mines, 1866, 6e sér., X, pp. 277–319; cf. also op. cit., 1854, 5e sér., VI, pp. 570–576 for coal.

[4] Fischer, Note sur la géologie du sud de Madagascar, Bull. Soc. Géol. de Fr., 1868,

There is no such sedimentary belt present on the east coast; only a few small volcanic mountains rise from the littoral plain.

So far as we are acquainted with it Madagascar presents a great resemblance to South Africa and India. The long, sharply marked, parallel terraces with scarps directed to the north-north-east which bound the central highland give it the appearance of an ancient horst. Upon this horst lie the sandstones of unknown age of the Isalo mountains, of Nossi-Bé, and other places. Volcanos are superposed upon it as upon the mass of Bohemia and the Central Plateau of France. The band of Mesozoic and Eocene deposits only girdles the west and south, and is completely absent in the east. It is a remarkable fact that in Madagascar, as in India, the rivers of the central mass find their discharge on one side only, and that here, as beneath the Sahyádri, the Mesozoic girdle is absent on precisely that slope the summit of which forms the watershed.

The *Seychelles*, situated far to the north-north-east, but precisely in the trend of the great horst, consist of granite [1]; Réunion, Mauritius, and Rodriguez are of volcanic origin.

*Summary*. An undeniable resemblance exists between the structure of South Africa and that of the Indian peninsula. Each of these two great regions has remained for a long time—Africa since the Carboniferous at least, India probably since the same period—undisturbed by any manifestation of tangential force; there has been no folding of the mountains, each is veritable table-land. In both cases we find, resting upon an older foundation, a mighty series of non-marine deposits which extend from the Permian to the Rhaetic and perhaps into the Lias. Throughout this long interval, a series of similar terrestrial floras, accompanied by peculiar land reptiles, flourished in both regions. Then came collapse. A new ocean was created and the continents assumed other forms. In the interior lofty table mountains formed of plant-bearing sandstone, or fragments of such mountains, still remain engulfed in troughs of the ancient foundation; the more recent formations which succeed, marine in Africa, and, from the time of the upper Gondwána, marine in India also, are deposited around them at a lower level against the new fractures. Out of the abyss of the ocean rises the great island of Madagascar, presenting all the characters of a horst; it likewise exhibits

2e sér., XXV, pp. 398–400; a Nerinaea with a broad base, which Fischer believes to be Cretaceous; further: Compt. rend., 1876, LXVI, p. 111, Phylloceras, Lytoceras, and Cosmoceras which pass as Jurassic; Sibree, loc. cit., p. 53: these fossils found in great quantity by Richardson in 1877 on the upper course of St. Augustine's river (= Onilahy); among them Ammonites, Nerinaea, Terebratula, and others.

[1] L. Pelly, On the Island of Mahi, Journ. Geogr. Soc., 1865, XXXV, p. 231: 'A mass of granite, emerging from a vast basin of coral growths'; C. Vélain, Mission de S. Paul, 4to, 1879, pp. 440–451. 'All the Seychelles are granitic except two,' says Wolf, Baracouta, II, p. 165.

fragmentary masses of sandstone resting on a granitic basis, and it likewise is bordered at a lower level by a selvage of Mesozoic deposits.

The theory of the original continuity of South Africa and India arose with the first recognition of their most elementary features, and has received for many years the support of the most distinguished authorities in both countries, as, for instance, Stow in Africa and H. F. Blanford and Griesbach in India [1].

Confronted by the stupendous scarps of the Karoo sandstone, which in so many places looks straight out to sea, Stow asks with justice, Where then is the boundary of the great basin in which so many thousands of feet of plant-bearing sandstone have accumulated? In India Blanford points out that in the east the volcanic outflows of the Deccan lie horizontal, but on the ocean side of the Sahyádri they dip so strongly seawards that in Bombay island their upper divisions are found at the sea-level [2]. In like manner Medlicott and Blanford point to the dissimilarity between the Cretaceous deposits of Bágh and those of Trichinopoli [3].

In quite another way, by comparing the distributional areas of existing organisms, eminent zoologists have been led to imagine the existence of an ancient continent on the site of the western half of the Indian Ocean, and to this vanished land the name of 'Lemuria' has been given. Other zoologists have rejected this hypothesis, adducing as one of the principal arguments against it the great depth of the sea near Madagascar, which frequently sinks to more than 2,000 or 2,600 fathoms.

I have, however, no intention of discussing here these differences of opinion; this could at best result in the solution of a much more limited problem, whether in the existing fauna and flora traces of an original connexion may still be recognized. This question, which involves the history of both continents, must first be approached by an examination of the structure of the continents themselves, of their existing outlines, and of the deposits which rest against their shores.

The analogy between the chain of the Quathlamba in the west and that of the Sahyádri in the east is so striking as to need no comment. Each represents the great fractured edge of a table-land. In detail, however, the existing margins of the two continents present some differences. The east side of the Indian peninsula is bordered by sedimentary deposits, which begin with the lower Gondwána and extend beyond the upper Cretaceous. The west side, up to latitude 20° N. and beyond it, has no border of this kind. In Madagascar the case is different; here the border is

[1] W. Stow, On the probable Existence of an Ancient Southern Continent, Quart. Journ. Geol. Soc., 1871, XXVII, pp. 546-548; H. F. Blanford, On the Age and Correlations of the Plant-bearing Series of India and the former Existence of an Indo-Oceanic Continent, op. cit., 1875, XXXI, pp. 519-542, pl. xxv, et passim.

[2] A section of this kind is given by Clark, op. cit., 1847, III, p. 222.

[3] Manual Geol. Ind., I, p. 297.

absent on the east side, but is present in the west and south, and extends from the Jurassic or Neocomian into the Eocene. In South Africa the case is again different. In the east of Cape Colony the deposits begin with the Uitenhage beds, which we have assigned to the lower Cretaceous; in Kaffraria they are absent; in Natal the upper divisions of the Cretaceous make their appearance.

Broadly taken the distribution of the marine formations is as follows:—

The middle and upper Jurassic, bearing European characters, proceed to Mombasa in Africa, and Cutch in India; their presence on the east coast of Madagascar is still doubtful. The supposed fragments of Jurassic on the east coast of India are also very doubtful, and perhaps belong to the following stage. The lower Cretaceous with southern characters, the stage of Uitenhage, appears on the east coast of Cape Colony, and vestiges of it are met with on the east coast of India, but in Cutch and the Salt range some indications are present (two species of Trigonia) which perhaps point to an encroachment of the southern type on the northern region.

At the time of the middle and upper Cretaceous the broad open sea extended from Europe over the desert, Arabia, and perhaps Somaliland, and Cretaceous deposits of south European character proceed through the valley of the Narbada into the interior of the Indian plateau. In the south, in Natal and Trichinopoli, and far towards the north-east up to the plateau of Shillong, between the Brahmaputra and Ganges, middle and upper Cretaceous are also present, but with a different facies, that of the southern hemisphere. Some species correspond with the European, but the great majority differ. It is therefore very probable that during this period no completely open communication existed between the seas of the north-west and the south-east.

During the Eocene period the open sea still spread over Arabia; the Nummulitic strata extend as far as Cutch and Guzerat, and to the east they cross the region of the Salt range and the Himálaya and reach, in the Shillong plateau, the region of the southern Cretaceous, which they overlie: thence they proceed far to the south-east. Towards the south they extend as far as the north-west coast of Madagascar, but they are absent in the south-east of Africa, the east of Madagascar, the whole west coast of India south of Guzerat, and the whole of its east coast; the deposits of Rájáhmahendri on the lower Godávari, which are perhaps to be assigned to the Eocene, depart too far from the normal type to enter into consideration.—

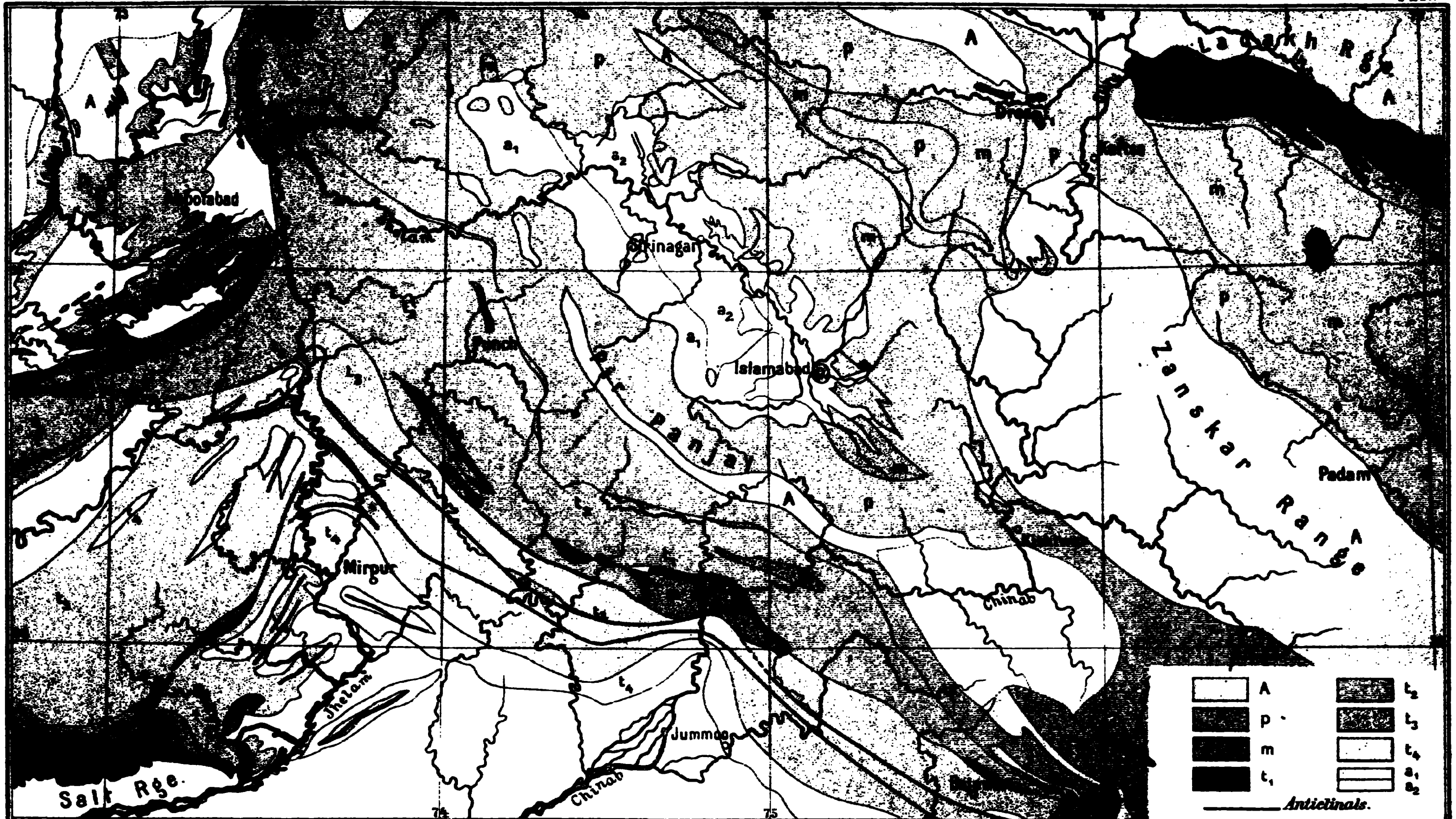
Thus it follows that since the Eocene period also important alterations must have occurred in the contours of the continents.

The conclusions which seem to me at present deducible, subject of course to modification by fresh observations, are as follows:—

India, Madagascar, and South Africa bear in common the stamp of

a once continuous table-land. In India the down-break began between the lower and upper Gondwána, i.e. probably during or after the Lias. In South Africa the epoch of this event cannot be precisely determined, but it is certainly later than the Trias and earlier than the Neocomian. Since then it has proceeded further. At the time of the middle Cretaceous there still existed a barrier running from south-west to north-east, perhaps not unlike that which further to the north now separates the fauna of the Indian Ocean from that of the Mediterranean; but the boundary between the two faunas was not so sharply defined as at present. In the Eocene period also, when according to Grandidier the Mediterranean deposits extended as far as Madagascar, some sort of separation still existed.

The table-lands of Arabia and the Sahara, formed from the sediments of the same Cretaceous and Tertiary seas, are now exposed as dry land. In this vast region also an ascending and a descending series, or in other words a superposed and apposed series, must be distinguished as near Suez; the limit between them in this case, however, falls in a much earlier period. Later on we shall proceed to inquire whether the collapse of continents so vast might not of itself produce a general lowering of the sea-level and thus bring about the emergence of the table-lands.




k.u.k. Hoflithogr. A. Haase, Prag

The Syntaxis at the Foot of the Hindú-kush and the Himalaya.

(See Cap. VII. Note 1.)

# CHAPTER VII

## THE SYNTAXIS OF THE MOUNTAINS OF INDIA[1]

**The exterior chains of Iran. The Salt range. The Tertiary chains. The western Himálaya. Mustágh and Kuen-luen. Hindu Kush and Pámir. The eastern Himálaya. Burma, Malacca, Sumatra. Summary.**

SINCE Alexander von Humboldt and Carl Ritter gave us the first outlines of a geography of the interior of Asia, numerous praiseworthy attempts have been made to determine more precisely the course and structure of some of the greatest mountain ranges of the earth. It is only in the course of the last few years that F. von Richthofen has described the structure of the north of China, that Przewalsky's adventurous travels have opened up a large part of Tibet, that united efforts have determined the arrangement of the crowded chains of the Pámir, and that, as the result of many years of devoted labour, Lydekker has published the geological map of the western Himálaya from the plain of the Indus as far as the glaciers of the nameless giant $K_2$ in the chain of Mustágh.

Nevertheless our knowledge of a great part of these mountains is even still extremely incomplete, and it therefore seems advisable to begin with the more generally known facts, and to be slow in drawing conclusions. We shall treat in this chapter of that part of the Asiatic mountains the structure of which is best known, and yet here too gaps are not wanting.

This region comprises the mightiest mountain ranges and the loftiest summits in the world. Their height in figures can only be cited with reserve, since it is believed that the numbers hitherto obtained are below the truth in consequence of a correction required in the coefficient of refraction, and it is also probable that to the north-west of Gaurisánkar

[1] The little map on Plate IV has been constructed from the maps published by the Geological Survey of India; the Himálaya as far as the Jehlam are after Lydekker, the Tertiary region east of this river after Medlicott, and the west after Wynne. The lines of disturbance of the Tertiary region are marked as anticlinals, but many of them are flexures dropped to the south; $A$ = Archaean; $p$ = ancient schists and Palaeozoic; $m$ = Mesozoic; $t_1$ = Eocene and Eocene volcanic sheets; $t_2$-$t_4$ = middle and upper Tertiary; $a_1$, $a_2$ = older and more recent alluvial land. The areas left white NE. and SW. of Abbotabad and S. of Kishtwar have not yet been mapped. With regard to the orthography employed in this chapter cf. note 1, p. 401; in treating of regions so different it was impossible to avoid inconsistencies, except by introducing a forced uniformity which would render the comparison of the original works more difficult. [The translator has in many cases followed the customary English spelling.]

[Mount Everest] peaks rise still higher than any which have hitherto been measured [1].

The highest known peaks rise at no very great distance from the plain of the Ganges in the southernmost gneissic chain of the Himálaya, and the contrast between the great summits and the plain coincides with a strongly marked contrast between folded chains and fractured table-land. At the same time some opportunity is here afforded us of studying the relations of great folded chains to one another and the manner in which they congregate together [*Schaarung*, or Syntaxis [2]].

The table-land has been discussed in the preceding chapter; there, as here, the excellent work of the Geological Survey forms the chief source of information. I should not, however, in spite of the abundance of material contained in its reports, have attempted so difficult a task, had it not been for the kind assistance I have received from many eminent colleagues, both in England and Russia. This will be apparent from the contents of this and the following chapter.

We learn from the Alps that their several branches are much more constant in course and structure on the arcuate outer border than on the inner side; we will, therefore, begin our study in this region also with the outer border.

Four arcs advance towards the Indian peninsula.

The first of these outer borders begins in the mountains of Kurdistan: it bounds the plain of Mesopotamia, follows the Persian gulf, trends more and more towards the east, reaches the mouths of the Indus, and extends thence to the north, almost following the river as far as the neighbourhood of Tank, north-west of Dera Ismail Khan. This is the outer border of the *Iranian* arc.

The second outer border differs in its structure from all other mountains of the world. It advances towards the Indus in a sharp bend, crosses the mountain Sheik Budín towards Puniála, then it recedes towards Kálabágh, where it is broken through by the Indus; on the other side of this river it proceeds again towards the south and reaches the river Jehlam near Jalalpúr. This is the Salt range, the outer border of the *Hindu Kush*. It is the shortest of the arcs.

From the Jehlam the outer border of the *Himálaya* strikes first to the south-east, then more and more to the east, finally to east-north-east, penetrating into the valley of the Brahmaputra opposite the wedge-shaped plateau of Assam. This is the third marginal arc.

[1] W. W. Graham, Travel and Ascents in the Himálayas; Proc. Geogr. Soc., 1884, new ser., VI, pp. 68–70 and 429–447.

[2] [The English equivalent for *Schaarung* is trooping, or trooping together. As a literal rendering would involve periphrasis, the word 'syntaxis' has been adopted in the translation. Note by Editor.]

From the valley of the Brahmaputra to the south of the plateau of Shillong the border of another mountain system appears; this at first strikes nearly parallel to the Himálaya to the west-south-west, then it bends to the south-west, and next fairly rapidly to the south, through Arakan to Cape Negrais, the Andamans, and the Nicobars. We may term the mountains to which this border belongs the *Burmese chains*, but they form only a part of a curved line of extraordinary length which in the north and north-north-west embraces Richthofen's 'System of Further India' (hinterindisches System), and in the south a large part of the Sunda islands; we shall call it as a whole the *Malay chain*.

*The outer chains of Iran.* The western part of the outer chains of Iran is formed of lofty mountain ridges which extend along the east side of the Tigris to the Persian gulf with a south-easterly trend, and then run more and more to the east. The whole of that part which is directed to the south-east we will distinguish as the chains of the *Zágros*. Loftus has crossed them in many directions and we will follow his descriptions [1].

In the lowland of Mesopotamia there emerges here and there from the alluvial plain a succession of flat-lying beds of middle Tertiary age, which are known as the gypsiferous series. They have a very wide distribution. Loftus believes that they correspond to the gypsum and salt deposits on lake Van, which, as we have seen, may perhaps be the equivalents of the gypsum and salt deposits of the Carpathians, that is, of the Schlier.

This gypsiferous series consists of three parts: at the summit a deposit of rolled pebbles, beneath this friable red calcareous sandstone, and finally at the base variegated clays with gypsum and sometimes salt. The asphalt which is found in the foot-hills of the Zágros also belongs to this series.

On the eastern border of the alluvial land rises the gypsiferous group, its folded and upturned strata forming a broad belt at the foot of the mountains, from Jezíreh-ibn-Omár above Mosul, in latitude 36° N., to Kazerun in 29° 47′. Their basset edges stand boldly out and find their prolongation in isolated patches which lie included in synclinal folds high up in the mountains, as in Lúristán, in the valley of the Kerkhah, on the Písh-Kúh at a height of 6,000 feet, and at Kirrind to the west of Kermanshah, where badly preserved marine shells are found at a height of 5,500 feet.

Below the gypsiferous series lies a great thickness of Nummulitic limestone. It rises in lofty anticlinal folds which are often many miles in length and are cut through by deep transverse ravines; here and there it forms almost inaccessible 'Diz' or fortified mountains. Such is the mighty Ban-i-Zardah between Bagdad and Sennah; on the south-west it ends

[1] W. K. Loftus, On the Geology of Portions of the Turko-Persian Frontier and Districts adjoining; Quart. Journ. Geol. Soc., 1855, XI, pp. 247–344, geol. map.

abruptly in the basset edges of a broken anticlinal, and on the north-east in a fault which has thrown down the whole mass of the 'Diz' separating it from the succeeding synclinal of which it forms the anterior part. It was on this block of Nummulitic limestone that Yezdíjird, the last of the Sassanides, made a final stand against the Moslim.

The Nummulitic limestone of the Zágros reaches heights of more than 10,000 feet; its folds traverse the whole length of the mountains, proceeding from the north towards the south beyond the ruins of Persepolis.

The next member of the series is the Cretaceous, also as a rule consisting of hard limestone. It runs from the mountains of Kurdistan through Lúristán, attains a great development in the Bákhtíyarí mountains, and then proceeds further to the south-east. A blue limestone which immediately underlies the Cretaceous may perhaps belong to an older Mesozoic group, but Loftus only suggests this as possible, and later observers, such as Blanford, are doubtful with regard to it. In a single locality in the midst of the Bákhtíyarí mountains, an Orthis of Devonian or Silurian age was found in grey limestone. Finally, as the foundation of all these deposits, Archaean schists appear in the eastern part of the mountains; they accompany a great granite zone coming from the north-west, which forms, on the eastern border of the mountains next the plain, the loftiest summit of the range, Mount Elwend, 13,780 feet high; thence it proceeds without interruption as far as the low chain of Fárajábad in latitude 32° 15′ N.

The chains of the Zágros, with their prolongations to Shiraz, present an asymmetric system of parallel folds formed by a movement from north-east to south-west. On its eastern border rises the granite of the Elwend, surrounded by ancient schists; towards the west follow the folds of the Cretaceous and Nummulitic limestone, and on the outer border next the plain the upturned gypsiferous series.

The succession of the strata presents a remarkable resemblance to that which we have met with in Arabia and in Egypt. In this respect there exists no such contrast between the Zágros and its foreland, as that of which the Alps afford so striking an example, and we might be tempted to say that the chains of the Zágros are only a folded fragment of the desert table-land.

On the inside of the chains of the Zágros, other ranges arise with a dominant trend to the south-east or east-south-east, and on the north side of the lofty Koh-Rud, between Káshán and Ispahán, Blanford and Tietze have found granite, while the south side consists of limestone [1].

We shall confine ourselves here, however, solely to the structure of the

[1] E. Tietze, Bemerkungen über die Tektonik des Alburgebirges in Persien; Jahrb. geol. Reichsanst., 1877, XXVII, p. 407. According to V. von Möller's investigations this limestone may possibly belong to the Carboniferous: Ueber einige Foraminiferenführende Gesteine Persiens, Jahrb. geol. Reichsanst., 1880, XXX, pp. 580-586.

outer border of Iran; that we can follow it still further to the south-east, we owe above all to Blanford, who has visited the coast at many points as far down as Cape Monze, has crossed the bordering chain of Gwadar on the journey through Jalk and Bampur to Kerman, and has furnished a detailed description of the ranges on the right bank of the lower Indus, which form the south-eastern part of the bordering mountains of Iran [1].

The coasts, as we learn from Blanford's account, are surrounded by a very recent marine deposit, the 'littoral concrete,' which reaches a height of only 20–25 feet above the existing strand; the next oldest member consists of horizontally stratified marine beds of great thickness; it is exposed along the whole of the south coast from Makrán almost to Cape Monze, and extends horizontally over the outer ridges and hollows of the mountains. Blanford distinguishes these beds as the Makrán group, and they appear to him to occupy here a position similar to that of the third or fourth Mediterranean stage in the basin of the Mediterranean; they are probably the same recent marine deposits as those which appear on the north coast o the Persian gulf, and in particular on the island of Karak near Abushakr.

On the islands in the straits of Ormuz, and probably also on the adjacent coast, variegated salt beds crop out in upturned strata from beneath the Makrán group; they are doubtless a continuation of the gypsiferous series of Mesopotamia.

Towards the interior now succeed Nummulitic limestone, Eocene marl and sandstone, and a great thickness of white Hippurite limestone. These extend from Shiraz towards the south-east, form folded chains far and wide, and then in Balúchistán proceed in long parallel chains running east to west past Píshín to Jálk and much further still. The Cretaceous is traversed in places by eruptive rocks of the same age. The basement is formed of gneiss, mica-schist, and talc schist; these rocks are visible near Saidábad, south-west of Karman, and on the border of the great plain of Narmashír, so that Blanford is led to suggest that they may extend in a continuous zone from the Elwend through the whole region of the Zágros and thence as far as the frontier of Balúchistán.

Finally volcanic rocks of more recent date are largely represented. To the north-east of the ancient rocks of Saidábad, just mentioned, they form the lofty mountains which extend nearly as far as Karman; towards the south-east, near Ráyín, the Kúh Házár, which is 14,600 feet high, belongs to them; they extend between Bam and Bampur, and on the other side they rise in the mighty but little known cones of Kúh-i-Basmán and Kúh-i-Nausháda.

[1] W. T. Blanford, Note on the Geological Formations seen along the Coasts of Bilúchistán and Persia from Karaché to the Head of the Persian Gulf, Rec. Geol. Surv. Ind., 1872, V, pp. 41–45; Eastern Persia, An Account of the Journeys of the Persian Boundary Commission, 1870, 1871, 1872, II: the Zoology and Geology, by W. T. Blanford, 8vo, London, 1872.

Thus the bordering chains of Iran, so far as they are known to us, present as far as Balúchistán the same structure and the same succession of rocks as in the north-west. There are, it is true, some indications, particularly in the orographic sketches of St. John, which suggest that, in the straits of Ormuz, two systems of outer folds, advancing in the form of arcs, join one another in syntaxis, and that the form of this arm of the sea is consequently determined by the course of the folds and by their relation to the Arabian foreland; in the strike of the inner chains no such syntaxis is known. They approach with a south-east trend the chains of Balúchistán, which run to the east and form the conjunction with the folded mountains of Sind [1].

The mountains on the lower Indus, the structure of which also has been made known chiefly by Blanford, begin with a short chain, running to the south-west, which dips beneath the sea at Cape Monze; of the other ranges I will only mention first the *Lakhe* chain, which advances towards the east—its northern end terminates near Sehwán and its front determines the bend which the lower Indus makes to the east—and next the long *Khirthar* chain, which runs in a slight curve from south to north between latitude 26° 15′ and about 28° N. These are composed of simple folds of moderate height, and in no part are rocks of greater age than the Cretaceous known. In the Lakhe chain, in full sight as it were of the ancient table-land of the Indian peninsula, the white Hippurite limestone crops out from beneath the Nummulitic beds; in the south-eastern part of its high ridges the outermost processes of the Deccan basalts appear; they have shared in the folding. Strata of the middle Tertiary period, in particular the marine group of Gáj, and the non-marine group of Manchar, which corresponds with the Siwalik beds of the Himálayan border, so famous for their richness in mammalian remains, are also folded and form a large part of these chains; but the still more recent, horizontally stratified, marine group of Makrán does not extend as far as Cape Monze and is not known in the valley of the Indus [2].

It is much the same in the western part of these chains; in the long stretch from Quetta to Kelát and to Gwujjuck on the Mushka in Makrán, a distance of about 380 kilometers, Cook has found no deposits older than the Cretaceous; the Eocene is associated with serpentine or dioritic rocks, or rests directly on them; their resemblance to those of south Arabia is pointed out by Carter [3].

[1] O. B. St. John, On the Physical Geography of Persia; Eastern Persia; An Account, &c., I; in particular orographic map, p. 6.

[2] W. T. Blanford, The Geology of Western Sind; Mem. Geol. Surv. Ind., 1880, XVII, pp. 1-201, map.

[3] H. Cook, Geological Discoveries in the Valley of Kelat and surrounding Parts in Beloochistan, in H. J. Carter, On Contributions to the Geology of Western India; Journ.

The south-westerly trend of Cape Monze, the advance of the Lakhe range to the east, and the northerly direction of the Khirthar chain gives to the mountains on the lower Indus collectively an elongated S-shaped form. North of Khirthar the much more important Suláimán chain advances again towards the west, but it is composed of the same rocks.

Griesbach going by way of the pass of Bolan and Kandahar penetrated into Afghanistan as far as Girishk on the Halmand; he crossed a large number of chains running to the south-west, but here also no deposits older than the Eocene and Cretaceous were met with. The Cretaceous limestones are traversed by contemporaneous eruptive rocks, especially near Kandahar; in some of the chains the Eocene is accompanied by Flysch; the middle Tertiary group of Gáj is not folded, but it rests unconformably on the rocks beneath, as far as the valley of Pishin, west of Quetta. Griesbach therefore regards the Cretaceous and Flysch mountains of Afghanistan as part of that vast region which, with an unchanging succession of strata, extends from the Karst, Herzegovina, and Greece through Syria and Persia up to the Indus [1].

Blanford has examined all the outer folds from the sea northwards as far as 30° 30′; the oldest deposits belong without exception to the Cretaceous [2]. In the north Griesbach has ascended Takht-i-Suláimán, the loftiest summit of the Suláimán chain, 11,300 feet in height, and here also no rocks older than the Cretaceous were discovered [3].

The observations hitherto made on the structure of the bordering mountains of Iran thus give a very definite and harmonious result. We see that from our starting-point, Jezíreh-ibn-Omár above Mosul on the Tigris, to our nearest approach to the Hindu Kush near Tank, not

Bombay Branch Asiat. Soc., 1862, VI, pp. 184–194. I have been unable to follow the example of other authors and to see in Cook's statement of the occurrence of Orthoceras in the Cretaceous limestone sufficient proof of the presence of older strata.

[1] C. L. Griesbach, Report on the Geology of the Section between the Bolan Pass in Biluchistan and Girishk in Southern Afghanistan; Mem. Geol. Surv. Ind., 1881, XVIII, pp. 1–60, map. The mode of intrusion of the eruptive rocks, which, near Kandahar, contain gold in the zone of contact, strongly recalls Posepny's observation that intrusions in limestone frequently take place in systems of cavities formed long previously by water.

[2] W. T. Blanford, The Geology of Western Sind, op. cit., 1879, XVII, pp. 1–210, maps; by the same, Geological Notes on the Hills of the Neighbourhood of the Sind and Punjab Frontier between Quetta and Dera Ghazi Khan, op. cit., 1883, XX, pp. 105–240, maps; also V. Ball, Geological Notes made on a Visit to the Coal discovered in the Country of the Luni Pathans, Records, 1874, VII, pp. 145–158, map.

[3] Griesbach in Medlicott's Ann. Rep. for 1883, Rec. Geol. Surv. Ind., 1884, XVII, p. 1. The accounts of its further continuation in the country of the Wuziri are incomplete and somewhat contradictory: Stewart and Oldham, Journ. Asiat. Soc. Bengal, 1861, XXIX, pp. 314–320, and A. M. Verchère, Kashmir, the Western Himalaya, and the Afghan Mountains, a geological paper, op. cit., 1867, XXXVI, part 2, pp. 18–20.

far from the Dera Ismail Khán on the Indus, these bordering mountains surround the higher country in such a way that only an insignificant part of the waters of the interior finds its way into the sea; next, that the outer folds probably form a special syntaxis in the straits of Ormuz, but the inner folds, however, are continued from the upper Tigris on towards Balúchistán, and thence with a change of direction to the Takht-i-Suláimán; and, finally, that in this great system of crescentic folds running from west to east, Hippurite limestone, Flysch, Nummulitic limestone, and Miocene beds are the prevailing rocks. The middle and lower parts of the Mesozoic system have not anywhere been observed; only Palaeozoic beds appear here and there, but as a rule the foundation, where it is visible at all, consists of gneiss and ancient schists. In addition eruptive rocks of Cretaceous, Tertiary, and even more recent age occur.

Deposits of recent horizontal marine strata apposed against older rocks are only known on the coast of Makrán and in the Persian gulf. In all other parts of the bordering mountains the most recent visible Tertiary deposits have been subjected to folding.

In front of the Iranian arc lies in the west the Arabian foreland, with an almost identical succession of strata; in the east, on the other hand, the arc is faced by the table-land of the Indian peninsula, totally different in character and distinguished by the long series of lower Mesozoic sandstones; just as different also is the succession of strata in the syntactic chains of the Hindu Kush.

The power and extent of the tangential movement may, as Blanford points out, be clearly realized from the fact that the road from Gwádar to Jálk in Balúchistán, nearly 240 kilometers long, crosses only vertical or almost vertical strata apparently of Tertiary age [1].

*The Salt range.* A common zone of folded Tertiary deposits encircles all the great Indian arcs. The outer border of the Hindu Kush, however, is distinguished from that of the other arcs, indeed from that of all other mountain chains known to me, by the fact that on its extreme margin *the older beds underlying the Tertiary foot-hills crop out in an abrupt step*, traversed by numerous fractures. This step, with which the flat, alluvial land of the Punjab comes into direct contact, is the Salt range.

The height of the alluvial land above the sea is about 750 feet, the mean height of the step above it is over 2,000 feet; the height of the culminating point of the Salt range, the Sakesar, is 5,010 feet. This step, which in many places resembles a broken antinclinal, is not rectilinear; on the contrary, towards Kálabágh, where the Indus enters the plain, it is so deeply inflected that the higher land which is bounded by it is divided into two plateaux, namely the high plain of Bannu, 1,000 to 1,500 feet high, and

[1] Medlicott and Blanford, Manual, I, p. lix.

the more extensive and almost equally elevated plain of Rawalpindi or the Potwar. The structure of the Salt range has been described in detail by Wynne, and Waagen has determined the age of its various strata [1].

The oldest visible deposits are salt-bearing beds and red sandstone; above them comes limestone with Productus and a great abundance of other organic remains: this has hitherto been regarded as the equivalent of the Carboniferous limestone; it is succeeded by beds containing Ceratites, which are assigned to the Trias; fossils of the middle Jurassic lie at a higher level, then follow black shales resembling the Jurassic Spiti shales of the high mountain chain, then greensand with Neocomian fossils, and finally the Eocene and the mighty series of Tertiary deposits. Several of these members present a marked resemblance to the strata of the Himálaya, and Waagen thinks that the whole series represents a transition from the sequence near Cutch to that of the high mountains [2].

The disturbances are extremely important; the strike of the separate parts, which together form the two arcs of the Salt range, changes rapidly and is bent in some places in a sigmoid curve; in addition to this the leaching out of the salt beds at the foot of the great step produces considerable local subsidences. In the west we first see a Tertiary chain running to the south-east; a second chain, striking to the south-west, advances towards it, and they meet in the south-west. At the southern corner rises the mass of the Makkum Gund or Sheik Budín (4,516 feet), presenting, as a consequence of a fold inverted towards the south, a large fragment of upper Tertiary embedded in the Jurassic. The fold going to the south-west is bordered on the east by a parallel ridge, in the eastern part of which the older formations are exposed; the fold then bends round in a sigmoid flexure, the convex border becomes concave, and the older formations appear on this side. Thus it reaches Kálabágh, where the second arc which surrounds the Potwar begins; the great horizontal dislocations and fractures in this locality are shown in Fig. 45. This second arc reaches the Jehlam in the east near Jalalpúr, and is then continued to the north in the Tilla chain, which is very irregular and is also curved in the form of an S (Pl. IV). Thus this short marginal fragment wedged in between the Suláimán chain and the Himálaya exhibits the maximum of disturbance in the greatest variety of form.

*The Tertiary foot-hills.* In the western Alps a very sharp line separates the region of the Molasse from the folds which lie towards the interior. This region begins with the lower fresh-water Molasse; the border is

[1] A. B. Wynne, On the Geology of the Salt Range in the Punjáb, Mem. Géol. Surv. Ind., 1878, XIV, p. 313 and maps; the same, On the Trans-Indus Extension of the Punjáb Salt Range, op. cit., 1880, XVII, part 2, 95 pp. and maps; W. Waagen, Salt Range Fossils, Palaeont. Ind., ser. XIII, 1879 et seq.

[2] Waagen, Geogr. Vertheilung fossiler Organismen in Indien, p. 8.

inverted towards the exterior so that the Molasse dips towards the Alps; from this limit it ascends, forming one and perhaps even two anticlinals, and becomes horizontal towards the plain. It has been repeatedly asserted by trustworthy observers that the intercalations of conglomerates in the

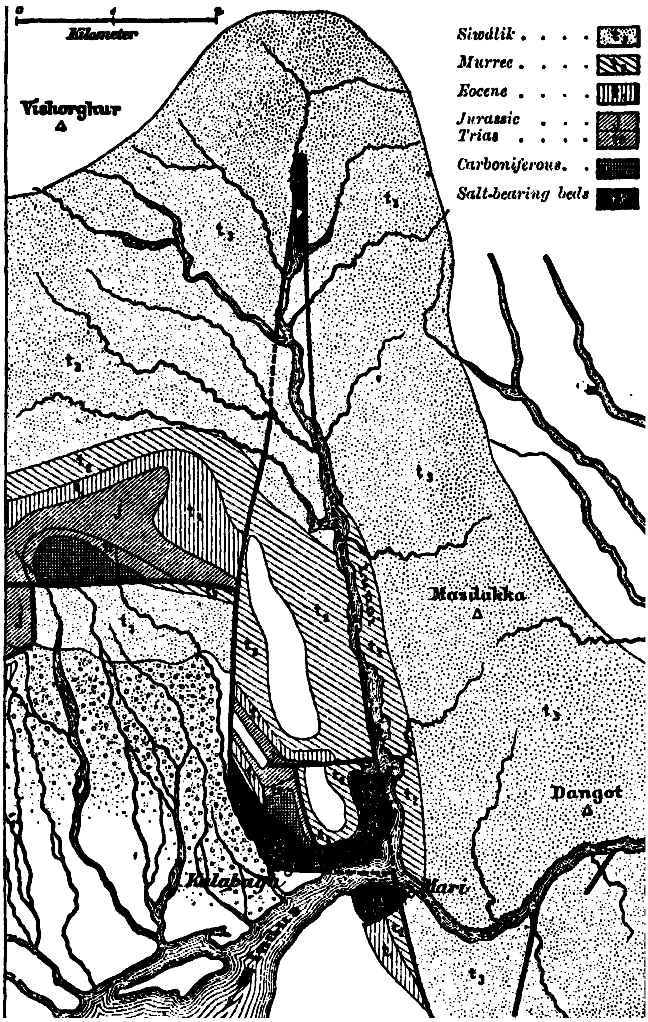



FIG. 45. *The Salt Range near Kálabágh* (after Wynne)[1].

Molasse appear at the mouths of existing transverse valleys, and from this it has been concluded that these valleys date from an early part of the Tertiary period, before the formation of the anticlinals and the overfolding of the border line.

[1] The extent to which the application of the terms Carboniferous and Trias must be modified will appear when Waagen's palaeontological investigations have been concluded.

In the eastern Alps two sharp limits of this kind exist. The first, which, wherever it has been studied in detail, is also found to be inverted towards the exterior, separates the great Flysch zone from the inner folds. The Flysch comprises Cretaceous and Tertiary rocks, and on the Canisfluc in Vorarlberg the underlying Jurassic crops out in a steep fold. The second sharp line separates the Flysch from the younger Tertiary country which lies in front of it, but, owing to the destructibility of the latter, this limit in the greater part of the northern border of the Alps is only marked by the continuous curve of the outer slope.

In the Carpathians the case is similar. The inner line is absent, but the underlying Mesozoic crops out in the series of *Klippen* as it does on the Canisfluc, and it is the outer line which separates the folded salt-bearing series from the Flysch.

A similar and equally sharp boundary line appears in the southern chains of the Hindu Kush and is repeated in the Himálaya. It separates these chains from a common zone of Tertiary formations, varying in breadth. This zone, which is everywhere sharply defined on the inner side, surrounds both these mountain systems. Its oldest member is the Nummulitic limestone, which, however, also occurs within the interior folds. All the stages of the Tertiary series which enter into the constitution of this zone are already present in the chains of Sind, that is, in the border mountains of eastern Iran, where they play an important part in the structure of the heights, but there is no sharp limitation towards the interior.

The line which separates the Tertiary zone from the chains of the Hindu Kush runs first from west to east, south of the Afridi mountains, then makes a slight deflexion on the Indus corresponding perhaps to the great indentation in the Salt range near Kálabágh, then trends to the north-east north of Rawalpindi (Pl. IV) and finally runs directly north to the syntaxis of the mountain systems near the Jehlam not far from Muzaffarabad. To the south of this limit the Tertiary land forms the already-mentioned plateaux of Bannu and the Potwar, which terminate in the Salt range on the south.

In the Himálaya the boundary line runs in a regular arc from the neighbourhood of Muzaffarabad far away towards the Brahmaputra, only advancing a little towards the plain as it nears the Sutlej. The Tertiary zone of the Hindu Kush crosses the Jehlam and is directly continued into that of the Himálaya. It is at first of considerable breadth, then suddenly becomes much narrower near the Sutlej, where the limit of the ancient formations advances towards the south, remains narrow over a long stretch and even disappears completely in Bhutan for a short interval, then reappears and is well developed in the valley of the Brahmaputra, crosses the latter above the mountains of Assam, and is continued in the Tertiary zone

of the Burmese chains with a sharp deflexion of the strike. The zone now runs to the south-west and finally to the south, so that, retaining a considerable breadth, it reaches the southern edge of the plateau of Shillong and at the same time follows the western border of the Burmese chains as far as the coast of Arakan. In Burma the same Tertiary deposits also enter into the constitution of the inner chains.

The Nummulitic limestone is present in the whole region of the Hindu Kush, and according to Medlicott, who has described the foot-hills of the Himálaya in a most instructive manner, it is continued in isolated outcrops as far as the above-mentioned constriction near the Sutlej. From this point onwards it is absent, and only the younger deposits accompany the mountains until far in the east the Nummulitic limestone reappears[1]. All the Tertiary deposits which appear above the Nummulitic limestone of the Hindu Kush and of the western and central Himálaya are of non-marine origin.

The marine group of Gáj, which is not unlike the marine Molasse of Switzerland intercalated between the upper and lower fresh-water Molasse, is found only in the most southerly part of the chains of Sind, which are elsewhere formed exclusively of extra-marine sandstone; it is only much further to the east, on the plateau of Shillong and in the east of Bengal, that marine deposits of middle Tertiary age again make their appearance.

The thickness of the non-marine Tertiary beds, which are superposed on the Nummulitic limestone, is extremely great; they include at least two distinct land faunas, and probably represent the whole period from the Eocene to the present day. Many of the younger deposits, such as the Siwálik series with its abundant mammalian remains, present so remarkable a resemblance to the most recent alluvium of the Indus and Ganges, now in course of formation, that they have been described as folded alluvial sediments of the existing river system. Concordant observations show that, as in the Swiss Molasse, intercalated masses of conglomerate appear near the mouths of the existing valleys. Lydekker remarks that pebbles of the rocks which form the interior chains appear in the Tertiary beds only at the mouths of those great valleys which at present penetrate somewhat deeply into the mountains, and that the Tertiary conglomerates which occur near the mouths of the shorter transverse valleys contain rocks of the adjacent chains only.

[1] Medlicott, On the Geological Structure and Relations of the Southern Portion of the Himalayan Range between the rivers Ganges and Ravee, Mem. Geol. Surv. Ind., 1864, III, 6, p. 208, map; the same, Note upon the Sub-Himalayan Series in the Jamu (Jummoa) Hills, Rec. Geol. Surv. Ind. 1876, X, pp. 49–57 (map, p. 155); Wynne, Observations on some Features in the Physical Geology of the Outer Himalayan Region of the Upper Punjâb, Quart. Journ. Geol. Soc., 1874, XXX, pp. 61–80, map; the same, Note on the Tertiary Zone and underlying Rocks in the North-West Punjáb, Rec. Geol. Surv. Ind., 1877, X, pp. 107–132, map; further, Manual, II, p. 517 et seq.

The inner side of the Tertiary zone dips beneath the high mountains, in consequence of a lateral movement coming from their direction, exactly as in the overfolded outer border of the Swiss Alps; and within the Tertiary zone itself long lines of disturbance occur which present an obvious resemblance to the long anticlinal fold of the Molasse. Here, however, we have the peculiarity that in the valley of the Jehlam two directions of curvature meet. A comparison of the valuable results obtained by Medlicott in the sub-Himálaya and the valley of the Jehlam, by Lydekker on the inner border of the sub-Himálaya as far as Muzaffarabad, and by Wynne on the deeply eroded plateaux of the Salt range, renders it possible to study the mutual relations of these two curves. This is all the more important, since we have some reason to see in these lines an expression of the general movements of the two mountain systems.

The outer folds of the Hindu Kush in Harzara appear, as is shown on Plate IV, to have pressed forwards somewhat further to the south than the adjacent parts of the Himálaya. We might, therefore, expect to find that a mighty dragging and overriding of the syntactic mountain chains had taken place in the Tertiary land of the Jehlam, but observations show us nothing of the kind.

The lines of disturbance are anticlinals, or flexures with a dropped outer limb; both for long distances are frequently overfolded towards the exterior, i.e. towards the south-west in the Himálaya and towards the south-east in the Hindu Kush.

We will begin with the region of the Himálaya.

A long synclinal follows the outer border of the ancient formations; it runs past Punch, approaches near Uri the place where the Jehlam leaves the ancient rocks, and appears to flatten out in front of Muzaffarabad.

Outside this line there rise at several places in the midst of the Tertiary land isolated masses of older limestone which, following Lydekker, we may regard provisionally as Mesozoic. Two such great masses in particular appear on the Chenáb: the first, Lapri, rises to a height of 9,914 feet; the second, Sangar Marg, is only 6,676 feet high, but nearly 50 kilometers long. Sangar Marg is obviously the outcrop of a great fold shoved towards the exterior, which is continued towards the north-west in similar outcrops. These are true 'Klippen' such as occur in the Carpathians.

Below the Sangar Marg two parallel lines of disturbance, of remarkable length, cross the Chenáb.

The first begins far in the south-east, crosses the Sutlej as a thrust plane overridden to the south-west, reaches the Chenáb below Sangar Marg after a course of more than 300 kilometers, and thence proceeds as far as the Jehlam. The second line lies nearly south of the first, and runs parallel with it to the Jehlam. According to Medlicott all the facts indicate that both lines, the one north of Mount Narh, the other south of

it, bend in a sharp curve and then pass uninterruptedly from the north-westerly trend of the Himálaya to the south-westerly trend of the Hindu Kush. Still further to the south a short arc, common to both systems, appears to cross the Jehlam transversely.

West of the Jehlam the tectonic lines are not so constant in their course. A certain number follow the direction of the ancient formations, and then, turning to due west, form the numerous parallel folds of the Eocene salt-bearing region in the district of Kohát. Wynne has followed them as far as Thal on the river Kuram, where the Eocene beds appear to bend sharply to the north around the Mesozoic mountain of Kadimuk; this probably indicates a syntaxis with the Suláimán range [1]. Another group of these lines trends more and more to the west-south-west. One of them, under the name of the Bakrala chain, strikes into the Salt range; in the southern part of its course the ancient strata of the Salt range are exposed. The already-mentioned much-fractured Tilla chain at the eastern end of the Salt range is simply one of these lines trending towards the Jehlam. Towards the west, within the Salt range, other lines emerge, which are directed towards the north-west and are consequently perpendicular to the line of Bakrala, as though in these foot-hills and in the first terrace of the Salt range an interference between the disturbances of the Hindu Kush and those of the Himálaya had taken place.

'This arrangement,' remark Medlicott and Blanford, 'exhibits in even a more convincing manner a synchronous action in both directions of disturbance. In this *struggle for room* this Salt range system seems to have had the best of it; flexures belonging to it are more persistent in overlapping the Himálayan series [2].'

*The western Himálaya as far as the Mustágh range.* The whole of this region has been so admirably described by Lydekker that his work on this subject must be numbered among the most important of recent contributions to a knowledge of the structure of mountain ranges [3]. To this we must add the attempt lately made by Godwin-Austen to furnish a general account of the whole of the Himálaya; this is based on so thorough a knowledge of the subject that it will be found of very real assistance in

[1] Wynne, The Trans-Indus Salt Region in the Kohát District, Mem. Geol. Surv. Ind., 1875, XI, pp. 101–330, map; by the same, A Geological Reconnaissance from the Indus at Kushalgarh to the Kuram at Thal on the Afghan Frontier, Rec. Geol. Surv. Ind. 1879, XII, pp. 100–114, map. The remains of an ancient eruptive mass appears on the Kurak. Further to the west our knowledge of the structure of the mountains is most incomplete, and we are quite in the dark as to the nature of their syntaxis. Sikarám (15,620 feet), the highest peak of the Safed Koh, consists of white quartzite; serpentine occurs near Ali Khel; near Jagdalak, east of Kabul, spinel is procured from white micaceous limestone: Proc. Asiat. Soc. Beng., 1880, pp. 3, 4.

[2] Manual Geol. Ind., II, p. 568.

[3] R. Lydekker, The Geology of the Káshmir and Chamba Territories and the British District of Khágán; Mem. Geol. Surv. Ind., 1883, XXII, pp. 1–344, map.

the task of mastering the mass of isolated observations now accumulated, although it displays a somewhat too prominent tendency to construct long continuous lines[1].

The first zone which we encounter beyond the Tertiary region shows the dangers of a too systematic conception. While in the south-east on the other side of the Sutlej a broad zone of less elevated mountains lies in front of the great snow-covered chains, on the north-west the border of the mountains advances somewhat further towards the Tertiary land, and from a chain of ancient rocks, chiefly slates, rise lofty jagged peaks of granite and granitic gneiss. Near Simla the mountain of Chor, 11,982 feet high, rises at a little distance from the Tertiary border; the broad mass of the Dhauladhár is connected by a narrow process with the *Pir Panjál*, much in the same way as the Iffinger, near Bozen, with the granite of Sterzing; at the same time the Pir Panjál is very much elongated in the direction of the strike, it attains at its northern extremity in the Tatakuti a height of 15,524 feet, and its continuation further is indicated by several small granite masses. The slates are altered to a high degree; spotted schists occur, and in the higher horizons numerous intercalations of volcanic products. MacMahon has shown from the nature of the granites of the Dhauladhár that these are in all probability intrusive masses; and thus, as regards this first chain of the western Himálaya, Indian geologists have arrived independently at results similar to those obtained in divers ways and by different observers in the Harz, in the Adamello, and many other mountain masses[2].

The course of this first chain, as may be seen on Plate IV, follows closely the direction of the lines of disturbance in the Tertiary region, and at the same time the whole range of the Pir Panjál is overturned towards the exterior, i.e. to the south-west, so that both north and south of the granite chain the inclination of the strata is towards the north-east. This tangential movement corresponds to the movements of the Tertiary region, and thus we find in this first chain the first proof of a unity of movement in the lofty mountain ranges and in the Tertiary foot-hills.

This chain may be followed as far as Kágán to the north-west, that is to say nearly to the meridian of Muzaffarabad.—

The zone of the Pir Panjál is followed towards the north by a zone striking in the same direction and composed of upper Palaeozoic and Mesozoic deposits; to this zone the great basin of *Kashmir* belongs. It

[1] H. H. Godwin-Austen, President's Address, Geogr. Section Brit. Assoc., Southport, 1883; also in Proc. Geogr. Soc., 1883, V, pp. 610–625; and by the same, The Mountain Systems of the Himálaya and Neighbouring Ranges of India, op. cit., 1884, VI, pp. 83-87, map.

[2] C. A. MacMahon, On the Microscopic Structure of some Dalhousie Rocks, Rec. Geol. Surv. Ind., 1883, XVI, pp. 129–144, pl. i; and the same, On the Microscopic Structure of some Himalayan Granites and Gneissose Granites, op. cit., 1884, XVII, pp. 53–72, pl.; Lydekker, p. 270 et seq.

begins in Chambra with a small synclinal, completely crushed towards the south-west, and the whole southern side of the great basin consists, as Lydekker has shown, near Islamabad in particular, of a long series of folds uniformly overturned to the south-west. Outcrops of Mesozoic strata occur along the borders of the basin, probably form its whole floor, and are continued with the same strike to the upper Kishanganga and in the direction of Kágán.

Now we reach the broad and lofty gneissose mass of *Zánskár*, 80 kilometers across, which terminates in a blunt end towards Kartse on the north-west and near this extremity reaches a height of 23,447 feet in the Nun Kun. It is supposed that this mass is continued beyond Lahol to the Nand Debi in the south-east and still further to the chain of the Gaurisankar and the Kanchanjanga.

The north-eastern side of the Zánskár meets that vast zone of fossiliferous deposits comprising all the strata from the Palaeozoic to the Cretaceous, which in its long extended course to the north-west constitutes one of the strongest proofs of the tectonic unity of the western Himálaya. Strachey has followed it as far as lake Manasarowar in Tibet, and recognizes it as the foundation of the broad table-land of Hundes; Stoliczka has determined the succession of its strata in the Spiti, and demonstrated the presence of a series of stages of the Alpine Trias; and Griesbach, completing these researches, has connected Strachey's field of observation with that of Stoliczka, and has shown the concordance of all the beds up to the Cretaceous [1].

Illustrations of this great zone are given on Plate I (folding of strata on an arm of the Bambadhura glacier) and Fig. 8, p. 109 (Mamrang pass). It forms as a whole a colossal synclinal, traversed by subsidiary longitudinal folds, and by numerous faults and thrust planes. Thus it embraces the mass of the Zánskár, bears in the middle of the synclinal, on the Pankpo pass, its last traces of Cretaceous, and, according to Lydekker, further to the north-east, on an inaccessible summit, a patch of volcanic rock, perhaps of Eocene age.

Near the river Suru, close to the end of the Zánskár mass, it appears to terminate, but Lydekker has shown that near Kartse isolated patches still occur, and these form the connexion with a much more extensive Mesozoic region, of triangular form, which continues the direction of the Zánskár mass (Pl. IV). This region consists at first of an anticlinal and two

[1] R. Strachey, On the Geology of Part of the Himalaya Mountains and Tibet; Quart. Journ. Geol. Soc., 1851, VII, pp. 292–310, map, and section. For the first observation of Alpine Trias, see Jahrb. geol. Reichsanst., 1862, XII, Verh., p. 258; F. Stoliczka, Geological Sections across the Himalayan Mountains, from Wangtu Bridge on the River Sutlej to Sungdo on the Indus, Mem. Geol. Surv. Ind., 1865, V, pp. 1–154, pl., and in many other places; Griesbach, Palaeontological Notes on the Lower Trias of the Himalaya, Rec. Geol. Surv. Ind., 1880, XIII, pp. 94–113, &c.

synclinals; the southern synclinal is overfolded to the south-west, and both finally unite in a long narrow wedge, the prolongation of which may be traced in isolated patches as far as the southern foot of the gigantic *Nanga*

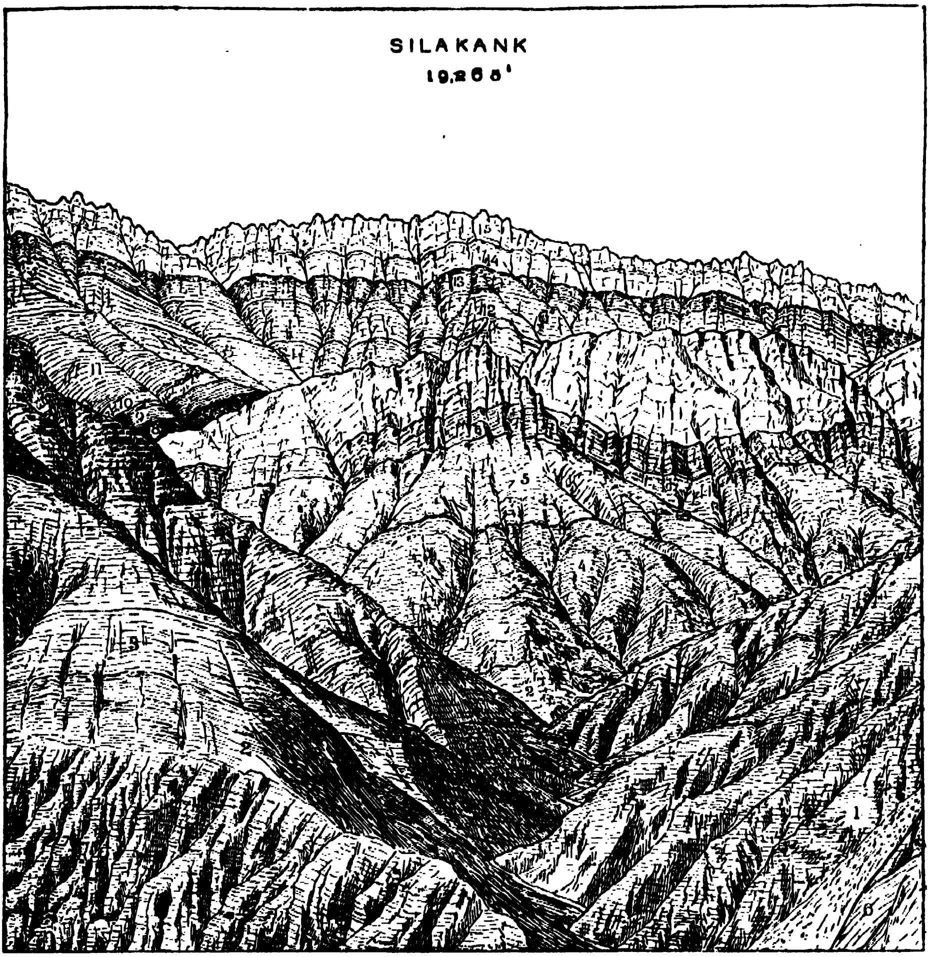



FIG. 46. *View of the Silakank* (after Griesbach).

1, Gneiss, hornblende rocks, granite; 2, Conglomerates and quartzite; 3, Red quartzose slates (Cambrian); 4, Coral limestone (lower Silurian); 5, Quartzite, &c. (upper Silurian); 6, Blue coral limestone (lower Carboniferous); 7, Red crinoid limestone, and 8, White quartzite (upper Carboniferous); 9, Productus horizon (Permian ?); 10, Otoceras beds, and 11, Muschelkalk (lower Trias); 12, Halobia beds, and 13, Dolomite with green shales, Corbis, &c. (upper Trias); 14, Dolomite, and 15, Kössener beds and Lithodendron limestone (Rhaetic).

On the north slope, on the other side, Lias; the Spiti shales of the Jurassic and Cretaceous follow in a vertical succession.

*Parbat* (26,629 feet); thence it is probably continued across the British frontier towards Chilas[1].

[1] G. T. Vignes, Travels in Kashmir, Ladak, Iskardo, &c., 8vo, 1842, I, p. 209, is quoted for the north-western prolongation; the passage appears to refer only to the neighbourhood of Gurez.

This arrangement of the Mesozoic rocks makes it seem very probable that in the northern prolongation of the Zánskár mass a regular covering of sedimentary deposits exists; although very much broken up and overfolded to the south-west, this forms the connexion between the two Mesozoic zones, that of Spiti (corresponding in great part to the Bara Lache of Godwin-Austen) and that of Kashmir.

The zone of which I have now to speak is the most extraordinary of all. Isolated patches of Eocene deposits appear west of the river Suru, near Draas, and to the east of this river. A continuous zone of Eocene sediments and eruptive masses, which extends far to the south-east in the direction of the Indus, joins the Mesozoic zone where it begins its long course to the south-east. The Eocene strikes slightly more to the east than the Mesozoic zone, so that a wedge-shaped mass of ancient rocks, increasing in breadth towards the south, comes in between and separates them. This wedge-shaped mass comprises the Tso Moríi in Rupshu and marks the commencement of a fresh zone of great masses of gneiss.

The intercalation of this wedge-shaped segment shows clearly that the Eocene zone represents an element absolutely distinct from the Mesozoic, and that important tectonic changes must have preceded the Eocene period. The Eocene zone has been followed for more than 300 kilometers, and towards the south-east it certainly extends for an even much greater distance; near Leh its northern border shows every indication of having been normally deposited on the gneiss of Ladakh: the southern edge, on the other hand, is formed by a fracture: further to the south-east the structure becomes complicated, owing to lateral pressure. The eruptive rocks belong to the southern side only. The Nummulitic deposits rise to very considerable heights: the *Kanri* or Stok, south of Leh, attains an altitude of 21,000 feet, and dominates for a great distance the mountains to the south. What changes are involved by the presence of this zone in the interior of the Himálaya, far to the north of the trend-line of the Nanda Debi! How great is the object of our research; how inadequate the conceptions with which we are accustomed to approach it!

The Eocene zone is followed by the broad gneiss and granite region of *Ladakh*, which, accompanied by many subordinate infoldings of Palaeozoic rocks, strikes across the plateau of Deosai towards Ronda and Gilgit.

Patches of Mesozoic deposits begin to appear again in Brulda. Granular limestone, such for instance as is mentioned by Lydekker at the foot of the Maskerbrum (25,676 feet), may doubtless be regarded, judging from observations made in the Alps, as representing these zones. A continuous, and sometimes fossiliferous, band of Carboniferous and Mesozoic rocks was found by Godwin-Austen near Shigar in Baltistán; this strikes first east and north-east, but according to Lydekker soon returns to the normal north-westerly strike of the Himálaya, and extends in this direction to the

east of Askola, as a fold inverted to the south-west, and much altered by pressure: it is then continued beneath the Biago glacier to the north-west, and probably even further beneath fields of ice which descend towards Hunga and Nagar[1].

Thus we have reached the northern frontier of the British possessions. To the south-west of the Mesozoic band of Baltistán lie Haramosh (24,285 feet), Raki Poshi (25,561 feet), and other giants of gneiss and granite which must accordingly be assigned to the zone of Ladakh; to the north of this band lies one of the mightiest mountain ranges on the face of the earth, the *Mustágh*. This also consists of gneiss and granite: Masherbrum, Gusherbrum (26,378 feet), above all the second highest mountain of the earth, the anonymous double-peaked summit designated by the British Survey $K_2$ (28,265 feet), belong to this range. It also strikes to the north-west, and the overthrusting near Askole, just mentioned, indicates that up to this point *the same tangential movement has prevailed as in the Tertiary hills of the southern border.*

*Kárákoram and the western Kuen-luen.* All the zones of the Himálaya hitherto discussed strike uniformly to the north-west or north-north-west, and in many places overfolding to the south-west may be observed. The Mesozoic band, which to the north-west of the great Zánskár mass grows narrower like a wedge and is continued at the foot of the Nanga Parbat only in isolated patches, is, as we have seen, continued a long way to the south on the other side of the Suru. On the plateau of Hundes, in Tibet, the gneissose chains, which lie to the north and south of it, diverge more and more from one another, but the divergence of the great bands of gneiss in this zone is slight compared with that which occurs in the north.

A limestone chain at first wedge-shaped gains so rapidly in breadth towards the east, north of the Mustágh, that the next succeeding line of older rocks, the Kuen-luen, deviating more and more from the direction of the Himálaya, assumes an easterly direction. It broadens out to the east, and finally forms a wide limestone tableland between the Himálaya and the Kuen-luen. To this limestone region belongs the well-known pass of *Kárákoram.*

We will begin in the east.

The southern border of the limestone mountains lies in Changchenmo, a lateral valley of the Shayok. On the north side of the valley, near Gogra, rise grey walls of limestone in which Dicerocardium and Megalodon are found; in the anticlinals this limestone is broken through by Carboniferous limestone. Directly we reach the summit, on climbing the northern side, we see stretching far and wide the high table-land.

The table-land is almost uninhabited. Only the most western part,

[1] Lydekker, op. cit., p. 192.

which lies to the north of the valley of Changchenmo, has ever been visited by Europeans. Adolf Schlagintweit was the first to cross this table-land; he was killed in Kashgar. Since then English geologists have explored it, but have hardly reached long. 80° E. A very graphic description is given by Drew. According to this, on approaching from the south, we first reach the broad plain of Lingzithang (17,000 feet), then the mountain range of Lokhzung (up to 21,000 feet), then the plain of Kuen-luen (16,000 feet), and finally the Kuen-luen mountains, which form the northern border and slope down to the plain of Khotan (4,000 feet)[1].

*Lingzithang* is a broad horizontal lake bottom, covered with white clay, within which lies the floor of a second lake, only about 20 feet deeper; the clay contains the remains of aquatic plants. Strand-lines occur on the slopes of the Lokhzung range, at least 150 feet above the plain; great saline pools lie scattered over the surface of the ground.

The Lokhzung mountains diminish in height towards the east: they consist of parallel ridges which strike to the west-north-west, that is to say nearly in the same direction as the principal ridges of the Kuen-luen. In this chain Drew has distinguished grey crinoidal limestone in steeply upturned beds, on which ferruginous sandstone and Hippurite limestone rest unconformably; the latter also frequently present a highly inclined dip.

The plain of Kuen-luen is more varied than that of Lingzithang; it is formed of a collection of lake bottoms which make up in number what they lack in size; nearly 4,000 feet above it rises the crest of the *Kuen-luen*, which at the egress of the eastern Kardash presents first an outcrop of schist and then of granite. The distance from the foot of the mountains to Changchenmo is about 170 kilometers.

The mountainous regions which succeed to the west have been traversed by F. Stoliczka along three routes which radiate from the bottom of the basin of the Tarim and are continued across the chains[2]. The first of these routes runs from Sánju (west of Khotan) through Shahidula and the western extremity of the Lingzithang to Changchenmo; the second proceeds from Karghalik over the Yangi Darwan, then towards the south-east, joining the previous route at Aktagh, then southwards through the Kárákoram pass and over the plateau of Depsang; the third turns to the south-west and from Yangi Hissar leads through Chenilgombaz, Chichiklik, and Tashkurgan to Ak-tash in the eastern part of the Pamir. The first route was traversed from

[1] F. Drew, The Jummoo and Kashmir Territories, 8vo, 1875, pp. 331–354. On our most generally used maps we find the name 'Thaldat'; this place lies at the north foot of the Lokhzung mountains. For this district cf. also G. W. Hayward, Journey from Leh to Yarkand and Kashgar, Journ. Geogr. Soc., 1870, XL, pp. 33–166, map.

[2] Scientific Results of the Second Yarkand Mission, based upon the Collections and Notes of the late F. Stoliczka, Geology by W. T. Blanford, 4to, Calcutta, 1879.

south to north, the second from north to south, and the third in both directions. In attempting a description of them I shall always start from the north.

The first two routes cross the Kuen-luen and the limestone zone which succeeds to the south; the third, which penetrates into the Pamir, meets the same rocks with a somewhat altered strike, a fact expressly and repeatedly insisted on by Stoliczka and of especial interest, since it leads to the important conclusion that *it is the Kuen-luen itself, deflected to the north-north-west, which forms that great mountain range to the west of Yarkand and Kashgar, usually known as the Kizilyart.*—

We first encounter, near Sánju (6,070 feet) at the edge of the basin, red Cretaceous sandstone and chloritic marl with *Gryphaea vesiculosa,* resting unconformably against the steeply dipping older schist. Above Sánju lies a zone of Carboniferous limestone, then follow ancient schists, which are partly chloritic schists and partly genuine mica-schists; near Tam, a patch of Palaeozoic appears to be sunk into them: garnet-bearing mica-schist forms the summit of the Sánju pass (16,650 feet); then, at the bottom of the Karakash, we meet with masses of gneiss, frequently syenitic, which form the principal crest of the Kuen-luen. The district immediately surrounding Shahidula is formed of this gneiss. Now we again meet schists, in great part certainly of Palaeozoic age, which form the pass of Suget (17,618 feet) and all the high land as far as the neighbourhood of Kizil-Jilga west of Thaldat, consequently the whole region west of the high plain of Kuen-luen, and here for the first time, near the camping-place Shing-lung (also Dong-lung), limestone appears with *Megalodon triqueter.* This point corresponds to the continuation of the Lokhzung mountains of Drew, and from here the Mesozoic limestone extends as far as Gogra in Changchenmo.

The second route meets a broad zone of very recent formations south of Karghalik, then grey dolomite and limestone, shales and greenstone, and beyond Chiklik the schist series of the Sánju pass. To the north of the Yangi pass the gneiss crops out. The pass itself, and the whole region as far as Aktagh, is formed of the schists mentioned on the eastern route, which are here accompanied by greenstone, while somewhat to the south of Aktagh Carboniferous limestone begins. This is overfolded to the south so that it overlies with a steep northerly dip Trias limestones rich in Ammonites. The Mesozoic limestone now continues on, and Lias with Belemnites forms the summit of the Kárákoram. The Depsang plateau is probably also formed of Lias, and the limestone zone extends southwards as far as the Sasar pass, which lies on the line of strike of the great Mustágh chain.

Thus in both sections the gneiss and syenitic gneiss do not appear on the heights, but strike to the north of the passes of Suget and Yangi.

Stoliczka made the journey from Yangi Hissar to Pamir before that

through the passes of Yangi and Kárákoram, but after that through Sánju, which had given him a first glimpse into the structure of the mountains. During the first two days he met with recent formations only, in part perhaps of Tertiary age. As soon as these had been crossed he recognized the schistose zone of Sánju and Tam of the first route, which is identical with that of Chiklik of the second route, and is here, as near Chiklik, accompanied by greenstone [1]. Traces of the red Cretaceous sandstone of Sánju also appear, and before arriving at Chiklik we reach the gneiss; between the Kokmainak pass and Tashkurgan runs a zone of mica-schist and hornblende schist. Then begins a second outcrop of gneiss and syenitic gneiss, which as far as Kogashak, near Aktash, is overfolded to the south or upturned against a ridge of Palaeozoic schist, which in its turn is succeeded by a lofty limestone range.

We are now in the eastern Pamir, on the upper course of the Aksu [2]. The limestone range just mentioned has afforded a whole series of fossils, and includes both Carboniferous limestone and Trias. Stoliczka met with it near Isstyk; near Aktash it strikes nearly due east, in front of Kanshubar it bends to the south-east, forms the highest parts of the pass of Neza-tash, and continues further to the south-east. When a little later Stoliczka reached the northern border of the limestone mountains to the north of the Kárákoram, he wrote in his diary, June 13, 1874: '. . . there is no doubt that this limestone extends to the south of Aktash.'

We arrive then at the following results: a fossiliferous Mesozoic band, which sometimes probably includes the Carboniferous limestone, appears in the eastern Pamir, striking nearly due east between Isstyk and Aktash; it soon turns to the south-east, crosses the Neza-tash, increases in breadth between the Mustágh and the Kuen-luen in the upper part of the Yarkand valley, and extends finally to the south as far as the Saser pass and towards Changchenmo. It includes within it Kárákoram, the high plain of Depsang, the Lokhsung mountains, Lingzithang, and all the high land as far as Kuen-luen, and is probably continued to the east into the Aksai Chin, i. e. the White Desert, and towards the Yeshil Kul.

To the north of this limestone region the Kuen-luen describe an arc so that they assume the direction of the Kizilyart; it is continued by two bands of gneiss near Chichiklik and south of Tashkurgan in those chains striking to the north-north-west which surround the basin of the Tarim on the west.

The correspondence between the curves thus obtained and the course of the Tertiary lines of disturbance is very striking. Even from the plains, in

[1] Op. cit. [note 2, p. 440], Diary of March 23 and June 3-8, 1874.

[2] Cf. Petermann's geogr. Mittheil., 1884, pl. iv. Aktash means 'white stone,' and the name appears to indicate the presence of calcareous rocks, as on a smaller scale Piz Alv in the Bernina.

latitude 33° N. onwards, we perceive that all the elements of which the chains of the Himálaya are composed tend to the north-west, then they sometimes bend round with a gentle curve into the direction of the Hindu Kush, at others abruptly assume a trend to north-north-west, as though they had been dragged out along a fault. The probability that this curvature of the Kuen-luen belongs to the same system of disturbance as the lines of dislocation of the Tertiary foot-hills is increased by the fact that not far from Aktash places occur where the gneiss is overfolded to the south upon the limestone.

*Hindu Kush and Pamir.* Our closer acquaintance with the southern chains of the Hindu Kush begins with the publication, in 1872, of the investigations of Waagen and Wynne on Mount Sírban, south of Abbottabad[1]. This work showed that even in these first chains the succession of strata observed in the neighbouring Salt range is no longer to be found, but that a series of deposits occurs which corresponds to the Mesozoic series of the Himálaya, that is of Kashmir and of the zone lying on the other side of the Zánskár, but particularly to that of the distant Spiti. Here that well-stratified grey limestone with Megalodon and Dicerocardium appears, which we have just traced far to the east of Chángchenmo on the plateau to the west of Lingzithang and which recalls so forcibly the eastern Alps. The Jurassic system is only represented by dark shales, as in the Spiti, and is thus distinguished from the Jurassic of the Salt range; above the lower Cretaceous lies an upper Cretaceous limestone, as in Chikkim. This correspondence is the more striking since the next succeeding ridge of the Himálaya, Pir Panjál with its elongated granite core, has furnished no organic remains from the Mesozoic period which can be recognized. There can be no doubt that these Mesozoic limestones, now folded and broken up, which form the different zones of the Himálaya from Tibet to the Kárákoram and the east of Pamir, were once deposited in a common sea, and we now perceive that this sea once also embraced the southern region of the existing Hindu Kush.

After investigating Mount Sírban, Wynne surveyed the southern chains, and from his researches we borrow the following facts[2].

The older rocks are sharply defined from the younger Tertiary land of Ráwalpindi by a very long arc-shaped dislocation, to which secondary

[1] W. Waagen and A. B. Wynne, The Geology of Mount Sírban in the Upper Punjâb; Mem. Geol. Surv. Ind., 1872, IX, pp. 331–350, map.

[2] Wynne, Observations on some Features in the Physical Geology of the Outer Himalayan Region of the Upper Punjâb, Quart. Journ. Geol. Soc., 1874, XXX, pp. 61–80, pl. vii; Note on the Tertiary Zone and Underlying Rocks in the NW. Punjáb, Rec. Geol. Surv. Ind., 1877, X, pp. 107–132, map; Further Notes on the Geology of the Upper Punjáb, op. cit., 1879, XII, pp. 114–133, with geological map of Hazára; also op. cit., 1882, XV, pp. 164–169; Waagen, Note on the Attock Slates, tom. cit., pp. 183–185; Lydekker, op. cit., 1882, XV, p. 14, and others.

dislocations run parallel for considerable distances. The arc-shaped dominant line runs from Muzaffarabad first to the south, then bends more and more to the south-west near Murree, passes into a westerly direction as it proceeds to the north of Káwalpindi and reaches Kohat. The overthrusting towards the exterior is so marked on this line, that, above Káwalpindi for example, the Jurassic shales rest almost horizontally on the Nummulitic limestone. In the south-east the outer border is formed by the Margalla range, composed of frequently repeated bands of folded Mesozoic and Eocene rocks; further towards the interior ancient schists prevail, and it is these which at some distance below Muzaffarabad form part of the syntactic chains and rise directly above the Jehlam to a height of from 8,000 to 9,000 feet above the sea-level.

Within the zone of schists, masses of granitic gneiss rise up and form the lofty mountains between Kunhar and the Indus and to the west of the Indus. The older schists correspond to those of Pir Panjál, and it is asserted that the granitic gneiss also is identical with the intrusive masses of the Dhauladhár and the Pir Panjál.

However this may be, it is certain that the general distribution of the rocks, as well as their strike, is determined by lines which are in complete accordance with the dislocations of the forelying Tertiary land, and that overthrusting towards the exterior may everywhere be observed. As to the east of the Jehlam the dip of the beds is towards the north-east, so to the west its prevalent direction is towards the north-west, that is, towards the higher mountains. It is always the same impulsion forwards which finds expression in all parts of these mountains.

In its exterior form this mountainous region is distinguished by a number of in-sunken plains, such as the plain of Pakli Dara in the north-east, which is let down into the ancient rocks like the caldron of the Hirschberg in the Riesengebirge; and again the great plain of Hazára, which is elongated in the direction of the strike of the chain and separated from the Indus by the band of slates forming the Gandgarh mountains: this presents more resemblance to the plain of Laibach in the eastern Alps than to the great synclinal of Srinagar.

Thus the first series of chains forming the Hindu Kush have followed, like the Himálaya, the same movements as caused the dislocations of the Tertiary country: the plan and direction of the disturbances are the same, but on a much grander scale.—

The ravine of Kunhar above Muzaffarabad in which the syntaxis takes place has been excavated in ancient schists and is surrounded by lofty mountains from which Nanga Parbat is said to be visible, though this already forms part of the gneiss chains of Ladakh. The structure of the country lying to the north or north-west of latitude 34° 30′ is unexplored. But the lofty Kunar chain, which bounds Káfiristán on the south, is known

to run to the north-east or east-north-east, in the same direction as that taken by the great principal chain of the Hindu Kush, from Kuh Baba, above Kabul, over the Khawak passes as far as the triple line of passes which lead from Chitral to Iskashim. Here the height of the crest is 16,000 feet, that of the Tirach Mir on a southern spur 25,426 feet [1]. From this point the mighty chain continues without change of direction, forms those snow-covered mountains, the northern slope of which faces the upper Paendsh, sinks near the pass of Baroghil to 12,000 feet, and then rises again, sending down great glaciers on the south towards Kunjud.

We have thus reached the upper course of the Oxus. As early as the summer of 1874, F. Stoliczka wrote to his friends in Europe: 'Pámir, the roof of the world, is not a plateau at all; it is a congregation of chains.' We owe it to the perseverance and devotion of Russian investigators that we are already able to form a general conception of these chains as a whole, and that their parallelism with those of the Hindu Kush is now definitely established. The decisive observations were made by Iwanow and his companions during their journey in the year 1883. I must here express my thanks for the information with which they have kindly favoured me [2].

According to Iwanow the following may be distinguished: the chain of *Wakhan* between the Wachan Daria and the river Pamir; the *chief chain of the Pamir* between the rivers Pamir and Alitschur; the *Alitschur chain* between this river and the Murghab; the *Murghab chain* which extends to the east-north-east as far as the pass of Ulugrabat; finally the *Rangkul chain*, north of the lake of the same name, which in the east forms part of the watershed between the Amu and the Tarim, and towards the west joins the *Karakul range*, which comes from Kokuj-bel and Tachtagorum.

These chains all run nearly parallel to one another from west-south-west to east-north-east; in the south they are followed in the same direction by the Hindu Kush, in the north by the chain of Sa-Alai and Alai. Towards the south-west they die away, but that steep fall common to all, which is marked on the maps between lake Shiva and the plain, does not exist; on the contrary a spur runs down as far as Rustak, west of Faizabad, and since Wood expressly mentions the north-east to south-west direction

[1] W. W. McNair, A Visit to Kafiristan; Proc. Geogr. Soc., 1884, VI, p. 9.

[2] I owe particular thanks to Herr Iwanow for the communication of some still unprinted accounts of a series of lectures delivered by him in the spring of 1884 before the Imperial Geographical Society of Russia. For an explanation cf. Petermann's geogr. Mitth., 1884, XXX, pl. iv, and Proc. Geogr. Soc., 1884, map, p. 176; these maps, as well as the provisory map published in the Iswestjia, were, however, prepared before the return of the expedition, and with regard to the points in question Iwanow gives his opinion against the statements concerning the course of the river Ges (to the north-east) as well as against those relating to the steep scarp with which Pamir is said to terminate towards the south-west in the direction of Faizabad.

of the lofty mountains of Khoja-Mohammed, I should be inclined to regard this also as a continuation of the chains of the Pamir [1].

Let us now consider the eastern side.

Stoliczka has shown that the Mesozoic limestone region of Kárákoram strikes across the passes Neza-tásh and Aktash, passing in a gentle curve from a north-west to south-east to an almost east to west direction, and thus reaches Isstyk, that is to say the northern extremity of the chain of Wakhan. Since Iwanow's observations are based not only on the direction of the mountain ranges but also on the strike of the rocks, it follows that the Hindu Kush, and with it the chain of Wakhan, lies to the south of the point where the zone of Kárákoram meets the line of contact of both systems of arcs, and that in the north of Kunjud the chief range of the Hindu Kush must either unite in a continuous curve with the mightiest chain of the western Himálaya, the Mustágh, or else meet it at an acute angle. The manner in which the boundaries of Kunjud and the upper Gilgit are marked on the map of the English survey points to the former of these hypotheses. Hayward indeed states expressly that the junction takes place at the upper end of the valley of Gilgit at a place called *Pusht-i-Khar*, i.e. the Ass's Back [2]. Directly south of this region lies the country of Hunza and Nagar; up to their boundary, beneath the glaciers of the southern slope of the Mustágh, Lydekker has traced the continuation of the Trias zone of Baltistán [3]. It is between this limestone zone and that of Kárákoram, Neza-tásh, that the gneiss chains of the Hindu Kush and the Mustágh must meet.

To the north of the limestone band of Aktash the case is different. Here, as we have seen, the Kuen-luen describes a great arc to the north-north-west and forms a long chain which, of no great height at first, rises rapidly beyond the pass of Chichiklik till it attains a height of 25,500 feet in the gneissose mass of the Tagarma (Mustághata) situated above the little Karakul, and on the other side of the lake it reaches 22,500 feet in an unnamed summit, and still continues in a long series of lofty peaks. This great chain, directed to the north-north-west and commonly called the Kizilyart, is accompanied by one or two shorter parallel chains: we will call it with Iwanow the *chain of Kashgar*.

The chains of the Pamir running to the east-north-east either abut directly on those of Kashgar running to the north-north-west, or terminate opposite to them.

[1] Capt. John Wood, A Journey to the Source of the River Oxus, 2nd ed., 8vo, 1872, p. 158. Beyond Rustak the lofty, isolated Umbar Koh near Kunduz might be added; cf. op. cit., p. 152.

[2] Hayward, tom. cit., p. 125. Hayward still includes the Mustágh under the name of the Kárákoram.

[3] Lydekker, Geol. of Dárdistán, Baltistán, &c.; Rec. Geol. Surv. Ind. 1881, XIV, p. 15, map.

From the pass of Kush-Bel, north-east of the pass of Kara Art, Iwanow looked down to the south into the valley of the northern Ges, and saw it bounded on the right side by beautiful mountain spurs, on the left by the lofty jagged chain of Kyrk-ku (Forty Peaks). The valley extends 70 kilometers to the west-north-west and north-west. Kyrk-ku is covered far down with snow, glaciers hang in every furrow almost down to the valley bottom. This is the northern continuation of the principal chain of Kashgar.

To this abrupt encounter of the two mountain systems we must ascribe the irregularity of the watershed between the Tarim and the Oxus; it passes across the region to and fro more than once.

*General view of the great Syntaxis.* If from the plain of India we approach the line along which the arc of the Himálaya and that of the Hindu Kush unite, we first encounter, near the river Chenáb, the mountains of Korána, a group of completely isolated hills advancing far into the plain, which, in sight of the first folds of the high chains, are composed of the rocks which form the table mountains of the peninsula.

These are followed to the west by the Salt range, a tier of land cut through by faults, which reveals to view the basement of the Tertiary foot-hills in front of the Hindu Kush. Then on the east and the west we reach the Tertiary foot-hills themselves, which are traversed by extremely long anticlinals parallel to the border of both systems, and by flexures which for long distances are overfolded towards the exterior. These lines meet in the neighbourhood of the Jehlam, and some of them appear to cross the line of encounter without interruption and to curve round from the south-easterly direction of the Himálaya into the south-westerly direction of the Hindu Kush. In the west some interference seems to have occurred owing to the encroachment of some lines belonging to the system of the Himálaya.

The contact of the Hindu Kush with the Tertiary foot-hills is indicated, as is that of the Himálaya, by long dislocations which also show overthrusting towards the exterior. In the Hindu Kush the arc described by the mountains advances much further south than it does to the east of the Jehlam, and below Muzaffarabad even the schist zone appears from beneath the Mesozoic deposits and is visible for a great distance along the right bank of the Jehlam; the gneiss and granite masses of Amb which then follow, appear in the Khágan above Muzaffarabad as the continuation of the first chain of the Himálaya. This is the Pir Panjál, with its intrusive granitic core, also overturned towards the exterior.

In the west observations fail until we reach the principal chain of the Hindu Kush, but in the east all the zones of the Himálaya, for the greater part overfolded towards the south-west, run parallel to one another and to the lines of dislocation in the Tertiary foot-hills towards the region of contact. The first of these is the Pir Panjál, then follows the Mesozoic

zone of Kashmir, the gneiss zone of Zánskár, the Mesozoic zone of Spiti which reaches the British frontier to the south of Nanga Parbat, the gneiss zone of Ladákh and the Mesozoic outcrops of Baltistán which strike beneath the glaciers of Mustágh towards Kunjud, and finally the gneiss chain of Mustágh.

Now we see the principal chain of the west, the Hindu Kush, meet in conflict the mightiest chain of the east, the Mustágh, and, as we said above, this encounter must take place in Kunjud.

The limestone region of Kárákoram-Lingzithang, which increases so rapidly in breadth towards the east, now advances from the south-east over Neza-tásh and invades the east of Pamir, again indicating the unity of structure in the whole; in the north, however, the Kuen-luen is deflected, first to the north-west, then to the north-north-west, forming the chains of Kashgar with the mighty Tagarma and the Forty Peaks.

In the west the Hindu Kush is joined by the long series of the parallel chains of Pamir, which meet abruptly the chains of Kashgar; the same direction is followed by the chains of the Alai, which belong to the Thian-shan. The chains of Thian-shan, however, proceed without deviation directly across the direction of the Kashgar mountains, and with them the great syntaxis terminates.—

The mutual relation of the great chains in this syntaxis resembles that of the subordinate dislocations in the Tertiary foothills. The first dislocation of the foot-hills appears to the west of the Jehlam on the outer side of the Salt range, in latitude 32° 45′ N. approximately; the pass of Kush-bel above the Ges lies north of 39°; the syntaxis extends through six to seven degrees of latitude. In the south it lies somewhat to the west of the meridian 74°, in the north somewhat to the east of it; its course is therefore north, and some degrees to the east. It is indicated in the south by the Jehlam, but in the north there are long stretches without a single valley to mark it. The mightiest chains appear to unite in a common saddle. This fact in particular bears witness to the unity of the movements. Like two shallow streams of lava, or two flows of slag running side by side, the waves of which as they cool come into syntaxis against a long line, now fusing completely together, now encroaching one on another, so the chains of the Himálaya meet those of the Hindu Kush.

*The eastern Himálaya.* Throughout the enormous length of the convex outer border from longitude 73° on the Jehlam to longitude 94° E. on the Brahmaputra, and probably even further to the east, the border of the mountains is as a rule overfolded and inclined in a contrary direction, i. e. towards the interior of the chains[1]. With this constancy of the most

[1] This reversed succession has been sometimes taken for the normal superposition, and the gneiss of Kanchanjanga has been regarded as younger than the lower Gondwána; sometimes it has been believed to show the original coast-line and subsequent collapse.

important and fundamental tectonic character, the difference between the various parts of the border as regards the nature of the deposits is the more remarkable; and although the observations so far made on this point are extremely fragmentary, yet they have already furnished results of no little importance in the study of general questions.

From long. 73° to about 77° E. there extend the lofty and jagged crests of the Pir Panjál and the Dhauladhár, a zone reversed towards the exterior, composed of rocks in which as yet no fossils have been found and penetrated by an intrusive granite core. To the east the outer zone decreases in height, and is called by Blanford and Medlicott the 'Lower Himálaya.' In this mighty series of apparently unfossiliferous sediments, known from the point where they leave the Jehlam as the Krol and the Blaini series, important bands of limestone and dolomite occur, which have been assigned in part to the Trias, but without sufficient proof. Near Simla this series, encroaching on the next zone which succeeds it to the north, attains a great breadth. On the other side of Kumaon observations are wanting for a great distance. Medlicott's expedition to Nepál, which penetrated to the shores of the Tirsuli Gandak, north-west of Katmándu, first threw some light on the structure of this country, as a rule so inaccessible to Europeans. The elements of which the outer zones of the great ranges are composed appear to be essentially the same here as in Kumaon [1].

Once more we are confronted by a great hiatus in the observations, and it is only at the frontier of Sikkim that we reach the field of F. R. Mallet's investigations, which embrace the outer border of the mountains almost from long. 88° to 90° E.[2] We must now enter into some detail.

To the east of Dárjiling the Ranjit joins the Tístá, and the latter then traverses the mountains, flowing from north to south. The transverse valley is excavated in green and grey slates (Dáling series), which separate from one another the extremities of two great masses of gneiss, the Kanchanjanga (28,516 feet) in the west and the Dánkia (23,189 feet) in the east. Dárjiling is built near the border of the western mass. The slate, however, not only separates these masses, it also borders both of them on the north and on the south, where the gneiss advances very close to the plain, and the slate dips on all sides beneath it.

Leaving the plain we see dipping steeply to the north-north-east, beneath the slate which supports the gneiss, a series composed of sandstone and

Although in the case of many more recent deposits the coast may have been near, yet those geologists who are familiar with the border of the Alps have at once recognized the universal overfolding, as, for example, Griesbach in Kumaon, Rec. Geol. Surv. Ind., 1880, p. 84, and L. v. Lóczi in the neighbourhood of Dárjiling, Földtan. Közl., 1883, p. 270.

[1] H. B. Medlicott, Note on the Geology of Nepál; Rec. Geol. Surv. Ind., 1875, VIII, pp. 93-101, map.

[2] F. R. Mallet, On the Geology of the Dárjiling District and the Western Duárs; op. cit., 1875, XI, pp. 1-96, maps.

fissile carbonaceous slate, in which many years ago Hooker discovered the first traces of plant remains. It is indeed a part of the lower Gondwána (Damúda) deposits of the peninsula, which dipping beneath the zone of slates and consequently also beneath both the gneiss masses of Kanchanjanga and Dáling, helps to form for a considerable distance the outer border of the mountains. The adjacent Tertiary zone, which is somewhat incomplete, is inclined here, as indeed everywhere, towards the interior of the mountains. The limestone bands of the Krol series have disappeared.—

The dip of the lower Gondwána beds and the slates towards the gneiss was at first interpreted as indicating a synclinal fold; it corresponds, however, to the inversion, which manifests itself in almost every locality where the border of the mountains has been studied. Since the northern girdle of slates similarly dips in a contrary sense towards the south, it is probable that both the masses of gneiss mentioned above possess a fan-like structure, and thus that the great outer mountain cores of the Himálaya are structurally similar to some of the great mountain cores in the outer zone of the western Alps, e.g. Mont Blanc.—

The Gondwána beds of the outer border of the mountains disappear again to the east; to the east of Joldoka limestone bands are seen, not unlike those of the Krol series of the west, and in long. 90° E. we encounter a fresh gap in the observations.

Much further to the east, in long. 93° 90′ to 94° E., where the river Dikrang emerges from the Daphla mountains, the limestone bands are again lost; on the other hand the coal-bearing Gondwána beds reappear. The observation of this remarkable fact is due to Godwin-Austen [1]. The Tertiary foot-hills extend in long folds with a north-east strike, and rise in the Gorusutia to a height of more than 3,000 feet above the Brahmaputra, presenting towards the plain of this river a scarp visible from afar. These folds are succeeded on their inner side by the coal-bearing Gondwána series, with a steep dip and very much compressed, particularly at the bottom of the longitudinal valley of the middle Dikrang; then follow immediately mica-schists, gneiss, and granite.—

Thus in the west and as far as Kumaun massive bands of limestone take part in the formation of this outer zone of the high mountains; this is also the case in central Nepál; in Sikkim the limestone disappears and is replaced by the coal-bearing beds of the peninsula; on the frontier of Bhutan the bands of limestone resume their position; in the Daphla mountains these are absent and the coal-bearing beds reappear.—

If we now consider the mountains, not in a longitudinal, but in a meridional direction, i.e. with regard to the adjacent regions in the south, then the general structure may be represented as follows:—

[1] H. H. Godwin-Austen, Notes on the Geology of part of the Dafla Hills, Assam; Journ. Asiat. Soc. Beng., 1875, new ser., XLIV, pp. 35-41, pl.

The highest known peaks of the Himálaya belong to the most southerly zone of gneiss, and this, at least in Sikkim, is divided into masses by bands of schist, like the gneiss of the Swiss Alps. On both sides of the Tista we must admit the existence of fan structure. The southern border of the fans of Kanchanjanga and Dánkia forms at the same time a part of the overfolded exterior border, which consists in part of lower Gondwána and younger Tertiary beds. The adjacent alluvial land of the Brahmaputra is diversified by isolated bosses of gneiss, and south of the river rises the gneiss of the long wedge-shaped plateau of Shillong, which, however, on the north side attains heights of only trifling elevation. An outflow of trap contemporaneous with the Gondwána lies against the gneiss in the south; the middle and upper Cretaceous overlie both horizontally; still further to the south follows the Nummulitic limestone, and finally the whole of the sedimentary series thus arranged descends in a great flexure to the south and south-east. At its foot lie, badly disturbed, the later Tertiary beds, and in front of us stand the folded chains of Burma.

*The Burmese chains.* The chains which I now propose to briefly discuss form one of the most extensive series of folds in the world.

According to existing accounts a number of parallel chains proceed from eastern Tibet, in the region about the head waters of the Irawadi, the Salwín and Mekong, and run from west-north-west to east-south-east[1]; they form Richthofen's 'System of Further India' ('hinterindisches System'). Their relations to the eastern end of the Himálaya are not known; but while they continue in the direction of Ta-li-fu and Momein, chains appear in the west, below the curve described by the Brahmaputra, which evidently belong to the same group; they form here the mountains of Nága, the Patkai and Barail chain above Cachar, and a long series of other ranges, which strike first north-east to south-west, and then with a somewhat sudden deflexion north to south; one of these, the long range of Arakan, extends as far as Cape Negrais.

The whole of Burma is traversed by an extremely well-developed series of longitudinal valleys running north and south; at the same time the course of the Malay peninsula and of the islands continuing its direction gradually undergoes a great and general deflexion from north and south to north-west and south-east as it proceeds southwards. The geological structure of this region, so far as it is known, is in accordance with these exterior features, and thus we are able to distinguish three great zones: a western zone, comprising the chains enumerated above, from the Nága mountains in lat. 27° 30′ N. to the Great Nicobar in lat. 7° N. and, as we shall see directly,

[1] Cf. the map by C. H. Lepper, The Singpho-Kampti Country or Neutral Ground between India and China, Proc. Asiat. Soc. Beng., March, 1882, pl. 1, and the map completed by B. Hassenstein, after Colborne Baber, Petermann's geogr. Mitth., 1883, XXIX, pl. 1.

still further to the south; a median zone, formed by the plain of the Irawadi and the adjacent sea; and an eastern zone which embraces all the mountains east of the towns of Ava and Mandalay and of the river Sittaung, as well as the whole of the Malay peninsula. The oldest rocks of the western zone are regarded as Trias; those of the middle zone do not extend further down than the Tertiary; the eastern zone is composed of much older rocks, principally Archaean.

Here too it is the structure of the exterior border which claims particular attention.

Mallet has studied the margin of the mountains along the Brahmaputra from lat. 27° 20′ N. to lat. 26° 30′ N. It consists of a coal-bearing series of middle Tertiary age and an older series of unfossiliferous shales and quartzite (Disang group) which proceeds through the whole of Arakan (Negrais group in the south). Both of these throughout their course dip in a contrary direction, i.e. to the south-east, and even if we assume with Mallet that the more recent coal-bearing series is separated from the older series by a long fracture, yet the reversed dip of both these tectonic elements again bears witness, as on the border of the Himálaya, to the extraordinary force of the tangential movement [1].

The Burmese border is separated from that of the Himálaya only by the valley of the Brahmaputra, and we have now before us a case in which two mountain chains approach one another, urged by *tangential movement in opposite directions.* To the north of the Brahmaputra the prevailing inclination of the strata is to the north-west, to the south of the river to the south-east; at the same time the convex sides of the arcs described by the two chains face one another, as well as the intervening wedge-shaped area of Shillong. In this region therefore we see complete antagonism in the tangential movement.

We now approach the plateau of Shillong; the outer arcs of the Burmese chains are at first separated from it by the valley of the Dhansiri, which flows round the north-east extremity of the plateau, before discharging itself into the Brahmaputra. It is at this point that R. D. Oldham has made known to us the folded zone in its entire breadth up to the great depression of the Irawadi. Several parallel chains exist here. The middle Tertiary reaches considerable heights; beds which are probably Cretaceous appear beneath it, then the older group of sandstone and shales, and towards the eastern border, that is to say, towards the border of the great depression, a long band of serpentine is seen [2].

[1] F. R. Mallet, On the Coal-fields of the Nágá Hills, bordering the Lakhimpur and Sibságar District, Assam; Mem. Geol. Surv. Ind., 1876, XII, pp. 269–363, maps. In the case of a fault the more recent series would also have been dragged upwards, not in this, but in an opposite direction.

[2] R. D. Oldham, Report on the Geology of parts of Manipur and the Nágá Hills; op. cit., 1883, XIX, pp. 217–242, map.

Recent Tertiary deposits extend from the outer slope of the Barail chains up to the plateau of Shillong, and even in the south-west, where the heights diverge towards Cachar, a horizontally stratified region of Tertiary beds appears between them. Their thickness is very considerable; many years ago it was suggested by Medlicott and Blanford that they may have been formed of ancient débris derived directly from the Himálaya, and that it was the compulsion of these sediments into the strike of the Burmese chain, in other words their incorporation into this system of folds, which caused the deflexion of the Brahmaputra to the north side of the plateau of Shillong [1].

The mountains of Lushai run to the south [2] in very regular parallel ranges as far as Pegu; Theobald has made a survey of this district, which, in spite of much uncertainty with regard to the age of the sediments, affords us very valuable information [3].

We will confine ourselves for the present to the western chain or the chain of Arakan. It is a single long fold, which proceeds from the northern chains down to Cape Negrais; its height sinks already in 17° 30′ to about 1,400 feet, and towards the south becomes still less. An older series is present, which from the presence of Halobia and Cardita is correlated with the Trias of the Himálaya; Cretaceous, as indicated by *Schloenbachia inflata*, occurs on the western flank near Sandoway; a considerable thickness of shales devoid of fossils, massive sandstone, and some lithographic limestone (Negrais series) forms a large part of the chain, then follow Nummulitic limestone and more recent Tertiary beds.

The chain as a rule is a simple anticlinal; the Trias crops out along its axis from the British frontier to about 19°, but just here the arch is broken towards the east, so that Nummulitic limestone comes in contact with the Trias; to the south the fracture disappears and with it the Trias, so that the normally constructed arch extends as far as Cape Negrais; the most southerly rock, Puriam Point, east of the mouth of the river Bassein, consists of Nummulitic beds. At the same time on the east side long bands of serpentine make their appearance, evidently in continuation of the band, which commences on the eastern border in 25° 10′ N.; these lie approximately between 19° 20′ and 17° 25′. But it is not only the course of the folding and the great longitudinal extent of the serpentine bands which

[1] T. D. La Touche, Notes on a Traverse through the Eastern Khasia, Jaintia, and N. Cachar Hills, op. cit., 1883, XVI, p. 203; Manual Geol. Ind., II, p. 699.

[2] 'Both to north and south the remarkable parallelism of the chains appears. . . . The peaks of the Uiphum chain, of which Klang-Sang (2,600 feet) is one of the highest, stand in a wonderfully straight line, so that a single plane table sight meets all the prominent points for many miles to the south. . . .' Capt. Tanner, The Lushai Expedition; Proc. Geogr. Soc., 1873, XVII, p. 49.

[3] W. Theobald, On the Geology of Pegu; Mem. Geol. Surv. Ind., 1873, X, pp. 189-359, map.

reveal the connexion between these chains: on the upper course of the river Dahing, which flows out of the Nága hills, in 27° 30′, salt springs and petroleum are known, and these recur in several places, as for instance on the island of Baránga, at the mouth of the Kolemin, on the islands of Rámri and Cheduba, where they are accompanied by mud volcanos, and as far as Cape Negrais. They are also present on the east side of these chains. Near Minbu on the Irawadi (lat. 20° N.) a mud volcano is known, and a large number of salt and petroleum springs occur as far as the sea. On both sides of the mountains they appear to belong to the Nummulitic beds or the middle Tertiary [1].

The combination of these characters, the long band of unfossiliferous sandstone and shales, at most of Cretaceous age, the salt springs, the occurrence of petroleum, the mud volcanos and the serpentines so forcibly recall the Carpathians, the Caucasus, and certain parts of the Apennines, that in Europe such a chain, notwithstanding the local outcrops of Trias, would be assigned to the Flysch. Among the mountains of India it is the chains of Sind which, with all their differences, resemble it most closely. The chain of Arakan does not, however, reach its termination at Cape Negrais. All observers, who since the time of Rink have studied the islands of the bay of Bengal, agree that it is continued through Preparis island and Cocos island on to the Andaman and the Nicobar islands. The strike is the same, the rocks also are the same, serpentine (here often associated with gabbro and greenstone), sandstone, shales, and younger Tertiary deposits, in broken folds, and surrounded by coral reefs [2], forming these islands.

[1] W. Theobald, Salt Springs of Pegu, op. cit., 1873, VI, pp. 67–73, map; Mallet, Mud Volcanoes of Rámri and Cheduba, op. cit., 1878, XI, pp. 188–223, maps; and Note on a recent Eruption in Rámri Island, op. cit., 1879, XII, pp. 70–72. Petroleum also appears in the Punjáb and at isolated points in Sind; in conclusion we must mention the mud volcanos of the sea-coast west of the mouths of the Indus, but the zones are nowhere so continuous as in this chain.

[2] F. Stoliczka, Die Andamanen, Verh. geol. Reichsanst., 1868, p. 192; V. Ball, Notes on the Geology of the Vicinity of Port Blair, Andaman Islands, Journ. Asiat. Soc. Beng., 1870, XXXIX, pp. 231–239, and Brief Notes on the Geology and the Fauna in the Neighbourhood of Nancowry Harbour, Nicobar, tom. cit., pp. 25–37; Medlicott and Blanford, Manual of the Geology of India, II, pp. 732–736; G. E. Bulger, A Visit to Port Blair and M. Harriet, Andaman Islands, Canad. Nat., 1876, VIII, pp. 95–103; further: H. Rink, Die Nikobarischen Inseln, 8vo, Kopenhagen, 1847, map, and F. v. Hochstetter, Beiträge zur Geologie und physik. Geographie der Nikobar-Inseln, Reise der Fregatte Novara, Geol. Theil, II, 1866, pp. 83–112, map; C. Schwager, Fossile Foraminiferen von Kar Nikobar, tom. cit., pp. 187–268, pl. Lydekker shows that the teeth of Diodon which occur in the Tertiary of the island of Rámri correspond with those of the sandstone of Port Blair, Andaman Islands: Rec. Geol. Surv. Ind., 1880, XIII, p. 59. Hochstetter (p. 98) has correlated these serpentines with the Tertiary serpentines of Italy, and Neumayr compares the whole chain to the Greek Flysch: Bittner, Neumayr, and Teller, Ueberblick der geol. Verhältnisse eines Theiles der Aegäischen Küstenländer, Denkschr. Akad. Wiss. Wien, 1880, XL, p. 405.

In following this western zone of the Burmese chains, we have passed from lat. 27° 30′ to lat. 7° N.; we will now leave it for a time and turn our attention to the central zone. By this we understand the whole region between the east border of the chain of Arakan, discussed above, and the eastern bank of the Sit-taung and of the Panboung, which flows into the Irawadi near Ava. It is, however, extremely probable that this zone is continued to the north, scarcely altered in breadth, far beyond the region of Bhamo; towards the south it comprises the whole of the sea basin lying between the Andamans and Nicobars on the west and the Malay peninsula on the east.

The first feature to arrest attention is a series of recent volcanos.

In the midst of the plain of the Irawadi there rises, not far from lat. 21° N., north-east of the petroleum springs of Yénân-Kyoung, and east of Pagân, the mighty isolated volcano *Puppâdoung*, which reaches a height of about 5,000 feet above the sea, while the height of Pagân on the Irawadi is only about 300 feet. The ascent has been made by Blanford. The crater sinks to a depth of about 2,000 feet; its wall is breached on the north side. Ash and lavas spread like a mantle over the adjacent part of the highland [1].

Far away to the south, in lat. 16° 22′ to the south of Nga-pu-tau on the lower Bassein, there rises above a stream of water bordered by old Tertiary beds the *Chouk-talon*, or 'lonely stone,' a small rock of trachyte which represents a dyke or a subsidiary eruptive centre [2].

The further continuation of this line is formed by the well-known volcanos of *Narcondam* (13° 24′) and *Barren island* (12° 17′) [3].

Apart from these volcanos the middle zone consists of three parts, namely, the valley of the Irawadi, that of the Sit-taung, and the long Pegu Yomah, which separates these two valleys.

The whole of the Pegu Yomah, the highest part of which, situated in 17° 55′, is said to reach 2,000 feet, consists, according to Theobald, of younger Tertiary beds thrown into gentle folds, and traversed by the eroded river valleys. Near the sea the deltas of the two rivers meet, the Pegu Yomah terminating near Rangoon; but in proportion as the plain of the rivers becomes narrower towards the north, the Tertiary range grows broader, so that from about lat. 19° it forms the whole of the central zone.

These Tertiary deposits are rich in marine shells; but we must

[1] W. T. Blanford, Account of a Visit to Puppâdoung, an extinct Volcano in Upper Burma; Journ. Asiat. Soc. Beng., 1863, XXXI, pp. 215-226, pl. Anderson quotes a volcano still further to the north in 25°; this lies, however, outside the region which I propose to discuss.

[2] Theobald, Geology of Pegu; tom. cit., p. 142.

[3] G. v. Liebig, Barren Island, Zeitschr. deutsch. geol. Ges., 1858, X, pp. 299-304, pl.; V. Ball, Barren Island and Narkondam, Rec. Geol. Surv. Ind., 1873, VI, pp. 81-90.

distinguish them from a more recent series which, while it contains true sharks' teeth, bearing witness to a communication with the sea, yet also includes a great quantity of silicified trunks of trees and the remains of a terrestrial fauna comparable to that of the Siwálik hills. From the description given by Theobald it would appear that this more recent stage rests against the marine beds at a lower level.—

From these facts we may conceive the past history of the Burmese chains to have been as follows:—

The formation of the depression which separates the Flysch zone of Arakan from the ancient rocks in the east must date from the middle of the Tertiary period. The sea which deposited the sediments of the Pegu Yomah extended very far to the north, forming a prolongation of the existing gulf of Pegu. During the subsidence of the strand the fluviatile and estuarine deposits were formed, in which the fauna of Siwálik is enclosed. This fauna corresponds most closely in age with that of the Pontic period. With further subsidence the existing state of things was brought about. The height at which the sea originally stood above the land cannot however be determined, since the elevation of the Pegu Yomah has been produced in part by folding; Bhamo on the Irawadi, more than 8 degrees of latitude north of the mouth of the river, lies only 430 feet above the sea.

Some resemblance may be found here to a much more limited region in Europe; the middle zone of Burma may be compared to the intra-Alpine depression of Vienna, which, partially separated from the outer region of the Alps by the fragments and spurs of the Flysch zone, must have resembled during the middle Tertiary period the ancient gulf of Pegu.

The eastern zone has been much less explored. We know, however, that the first chain, the Poungloung range, which rises to the east above the river Sit-taung, consists of Archaean rocks, but that near Moulmein on the Salwín an extensive mass of Palaeozoic deposits appears. The limestone rocks which belong to the upper stage of these deposits have furnished Carboniferous fossils. It seems, according to Theobald, as though these Palaeozoic beds, isolating the Poungloung chain, are continued far to the north in the valley of Salwín, and in the south find their further prolongation in the steep limestone rocks which form the Mergui archipelago[1].

The Archaean rocks, which are known in Tenasserim east of the Palaeozoic zone of Mergui, form the isthmus of Krau, and all existing descriptions seem to indicate that the whole south of the peninsula is formed of granite, Archaean schist, and Palaeozoic beds. In any case,

[1] Theobald, Geology of Pegu; tom. cit., p. 223, Manual Geol. Ind., II, p. 709.

according to Tenison-Woods, the general structure of the country does not coincide exactly with the strike of this southern part. On the contrary, a western group of parallel chains occurs in Perak, which begins in the state of Kedah, and produces the broadening out of the peninsula: this group includes also Penang and the Dinging islands; it runs north-north-east to south-south-west and rises to a height of almost 7,000 feet. To the east of the river Perak a shorter chain succeeds, running north and south; to the east of this again rises the principal chain [1]. Near Singapore granite occurs, accompanied by other massive rocks, ancient sandstones and shales; the direction is north-west [2].

*Sumatra.* The sea of Pegu, the continuation of the great Tertiary gulf of the Irawadi, narrows towards the south; the great island of Sumatra juts forth, and upon it the rocks of the Nicobar islands find a meeting-place with those of the peninsula of Malacca, as we can perceive from the works of Dutch geologists.

Indeed the valuable researches of Verbeek and his colleagues show us that few new elements appear in Sumatra [3]. Extensive masses of older schists are present, more recent intrusive granite, shales and limestones of the Carboniferous system, a series of eruptive greenstones, particularly diorite and diabase, a fairly diversified Tertiary series, finally middle Tertiary andesites and great modern volcanos.

The whole line of the islands to the west, from Pulu Babi and the island of Pulu Nias, famous for its rich beds of coal, through the Mentawei islands as far as Pulu Engano, consists of Tertiary deposits, and thus forms an independent exterior zone. On Sumatra itself, of which it is true the southern and central parts alone are known in detail, the rocks mentioned above are thrown into numerous folds and intensely fractured. These rocks are traversed by two very long volcanic lines trending in exactly the same direction as the island itself, i.e. to the north-west. The first of these runs close to the west coast; it is of Miocene age and is marked by a long series of outcrops of andesite. The second line is the great axis of the existing volcanos. This extends over the whole length of the island, which amounts to 1,117 kilometers, and from lat. 6° S. to lat. 2° N., or as far as detailed observations extend, it is crossed by no less than twelve

[1] J. Errington de la Croix, Le Royaume de Pérak, Bull. Soc. géogr., 1883, 7e sér., IV, pp. 333–352, maps; J. E. Tenison-Woods, Geology of the Malayan Peninsula, Nature, 1884, p. 76, and Mountain System of the Malayan Peninsula, tom. cit., p. 264.

[2] J. R. Logan, Notice of the Geology of the Straits of Singapore; Quart. Journ. Geol. Soc., 1851, VII, pp. 310–344, map. L. v. Lóczi says that the appearance of the sediments which overlie the granite near Singapore resembles that of the Alpine Flysch: Földt. Közl., Sitzg. ung. geol. Ges. v. 5. Jan. 1881.

[3] We will only mention the last and most important work: R. D. M. Verbeek, Topogr. en geol. Beschrijving van un Gedeelte van Sumatra's Westkust, 8vo, Batavia, 1883, Atlas in 8vo and 4to. The petroleum springs of the north recur on Sumatra.

short transverse clefts, which resemble those of the volcanic zone of central America (Fig. 5, p. 93), though not so regularly arranged. Standing over this system of fissures as far as lat. 2° N. are fifty-nine volcanos at present known to us, and if we include those of the first transverse cleft, which runs past Krakàtoa to the Goeneng Pajoeng at the north-west corner of Java, the number rises to sixty-six. Of these eight are known to be active, among them the notorious Krakatoa, Dempo, 3,167 meters in height, Korincha, about 3,600 meters, and others. In addition several other eruptive centres certainly exist in the north of the island [1].

Here we have a case not of caldron-like in-breaks on the inner side of a folded chain, but of longitudinal fracture of the chain itself, and that on the grandest scale. The older line of fracture dating from the middle Tertiary period lies to the west of the present zone of volcanos, and consequently outside it, for both lines are distinctly convex towards the south-west, following the direction of the great Malay arc. The modern volcanos rest on the previously formed folded mountains, and the foot of their ash cones adapts itself to the valleys eroded in them, a conclusive proof that their appearance is a much later phenomenon, subsequent to the folding of the mountains, or at most accompanying only its latest phases.

The network of fissures, however, seems to indicate that the whole island will one day be broken up, as its prolongations have been already; and if this general collapse should really take place and these or perhaps fresh volcanos should continue to build up their ash cones from the bottom of the subsidence, then nothing finally would be left to view on the site of the folded mountains but a number of volcanic islands, like Barren island and Narcondam.

Java is indeed a double series of such volcanos, superposed on a Tertiary base, with some Flysch and serpentine; many years elapsed before even isolated traces of the older schists of Sumatra were discovered on this great island [2]. To the east of Java the destruction of the great arc-shaped chain has advanced even further, and its fragments extend beyond Timor. Their detailed investigation does not now concern us.—

Martin not unjustly points out that the line drawn by Wallace on faunistic evidence to the east of Bali and Borneo as the boundary between Asia and Australia finds no confirmation in the geological structure of the islands [3].

Quite as little, however, in the case of the West Indian islands, does the

[1] Verbeek, op. cit., pp. 398 et seq., Atlas, 8vo, pl. xii.

[2] Verbeek and R. Fennema, Nouveaux faits géologiques observés à Java; Arch. Néert., 1881, XVI, pp. 48-64.

[3] K. Martin, Die wichtigsten Daten unserer geolog. Kenntnisse vom Niederländisch-ostindischen Archipel; Bijdr. tot de Taal-, Land- en Volkenk. en Ned. Ind. uit p. t. Geleg. van het VI. Intern. Congress d. Orientalist. te Leiden, s'Gravenhage, 1883, p. 27.

boundary between Anguilla and St. Christopher, indicated by the terrestrial Mollusca, coincide with a geological boundary. There, too, the dividing line passes transversely across chains of islands which form parts of the same mountain range. This is characteristic of separation caused by subsidence, and is in accordance with an earlier assertion of Wallace, that the Malay archipelago 'presents the characteristics of a broad continent with special fauna and flora, which has been *gradually* and *irregularly* broken up[1].' Under these circumstances, and considering the great depth of the sea between these islands, very little importance must be attached to the very general but inconsiderable oscillations of the strand-line, which belong to another group of phenomena. This is the same result which we obtained by another method in the case of the Mediterranean.

*Summary.* Four great arcs advance towards the south, which we have termed the Iranian arc, the arc of the Hindu Kush, the arc of the Himálaya, and the Malay arc. They meet in face of the Indian tableland, which stands opposed to them as a foreign mass and separates them. The movement towards the south is most strongly expressed in the two middle curves and indeed in the overthrusting of the whole stratified series, which thus appears inverted for great distances. In the southern parts of the Iranian arc on the Indus, as well as in the southern part of the Malay arc in Arakan, only long anticlinal folds have been formed without overturning; in the valley of the Brahmaputra, however, opposite the border of the Himálaya overfolded towards the south-east, an overfolding of the Malay border has taken place and in the opposite direction, namely to the north-west.

Similar as are these arcs themselves in their course and character, yet the areas they bound, which form as it were their hinderland, are not precisely homologous.

The plateau of Iran, as far as it is known, presents the same succession of strata as the outer curve. In the west there is complete parallelism between the north-west continuation of the Albourz and the Zágros chains, and we shall soon see that on the south-east shore of the Caspian sea two gently curved interior arcs meet one another. The Iranian arc is thus only the outer part of a great plain traversed by folds arranged in a uniform manner, and this plain is homologous with the border itself.

The chains of the Hindu Kush—from the Salt range and the Tertiary folds and flexures of the south through Hazára, and the lofty chains which

[1] 'Gradually and irregularly broken up:' A. R. Wallace, On the Physical Geography of the Malay Archipelago, Journ. Geogr. Soc., 1863, XXXIII, p. 233. According to this view the Philippines were first detached, Java much later, a little later still Sumatra and Borneo; finally the islands south of Singapore as far as Banca and Biliton: Wallace, Island Life, 8vo, 1880, p. 362.

succeed them so far as they are known, through these to the Pámir and the Thian-shan—likewise reveal themselves as parts of a great general system of folds, which extend from the far north to the low-lying plain of the Indus, *in a state* of extreme compression, to which the frequent changes in trend of the Salt range bear witness.

The Himálaya also belong to a very broad region, which has been subjected to a uniform movement, and the overfolding of its outer border is repeated, at least in its western part, far to the north, even on the southern border of the Mustágh, to the north of Kárákoram, and even it would seem as far as the point where the north-west part of the limestone zone of the Kárákoram enters the Pámir. In this folded region we also include the western Kuen-luen, but where this swerves to the north-west transgressions of Cretaceous deposits occur at its northern foot, and these afford grounds for the conjecture that it is a foreign mass with a different succession of strata, situated beneath the valley of the Tarim, which has caused the deflexion of this mighty chain and its divergence from the Thian-shan.

Further to the east, however, this divergence no longer exists. Przewalski has shown how north of the Kuen-luen the mighty chains of the *Altyn-Tagh* and *Nan-shan* insert themselves, and the picture which this enterprising traveller has drawn of the country between the meridian of Lob Nor and that of Kuku Nor, and from lat. 32° to 46° N., shows (through 10 degrees of longitude and 18 degrees of latitude) a uniform development of nearly parallel chains. Subsidiary parallel chains occur even in the middle of the desert of Gobi. This vast region comprises a part of the Mongolian mountains, the eastern Thian-shan, the desert of Gobi south of Chami, Altyn-Tagh and Nan-shan with the Humboldt mountains, the South Kukumor chain, Kuen-luen with its ancillary chains and the mountains to the south of it, Tan-la and also Ssamtyn-Kansyr of the Tibetan Himálaya. All these chains run to the east and slightly south, with secondary deflexions to the east or east-north-east, whereby occasional intersection results, and an elongated more or less net-like arrangement, in which, however, the great general direction to the east, somewhat south, is still clearly manifest. Only the *Ritter chain*, a short isolated transverse branch on the south side of the Nan-shan, appears as running to the north-east[1].

The explorations of the Pundits—especially those of the intrepid Nain-Ssing, who obtained Cretaceous fossils from Lake Namcho, 120 kilometers north of Lhassa—show, however, that it is the same system of folds which, assuming an arc-like form, extends to the outer border of the Himálaya,

[1] N. Przewalski, Third Journey into Central Asia, IV: from Lake Saisan to Tibet (in Russian), 4to, Petersb., 1883; the map also appeared on a reduced scale in Petermann's geogr. Mitth., 1883, pl. ix; also Przewalski, Northern Tibet, tom. cit., pp. 14-23.

where it forms, in the meridian of Lob Nor, the overfolding of the border in Bhutan [1].

This region probably possesses the greatest breadth of any uniformly folded region in the world; measured perpendicularly to the folds it extends from Bhutan into Mongolia, i. e. through more than 22 degrees of latitude or about a quarter of a terrestrial quadrant.—

The Burmese chains advance very far to the north-north-west; the way in which they encounter the great east to west chains is not known, but we hope for information on this point from Széchény and Lóczi, who have travelled through their northern part. This remarkable journey led the explorers into the great folded region on the northern declivity of the Nan-shan and on the Kuku Nor, of which we have just made mention, and Kreitner's preliminary report lends confirmation to the view that a large part of the chains seen by Przewalski, which run to the east-south-east, and especially those between the Himálaya and the Kuen-luen, bend from east-south-east to south-east and south-south-east, and finally to the south towards Ta-li-fu and Bhamo. In this case there would be no syntaxis of the Himálaya with the Malay arc, but the Malay arc would be the prolongation of the interior chains of Tibet [2].

We know that in the north a considerable number of closely crowded parallel chains occur, while further to the south a part of these has disappeared beneath the plain of the Irawadi and the sea of Pegu. In the interior of the Malay arc, however, Mesozoic plant-bearing beds appear, which correspond to a part of the Gondwána series of the Indian peninsula [3]. Many circumstances seem to indicate that Cochin-China and Tonkin are ancient table-lands. It is by this that the Malay arc is fundamentally distinguished from the western arcs. A fresh difficulty thus arises in tracing the connexion of the mountain ranges. Added to this is the subsidence of great chains beneath the sea, and the incomplete state of our knowledge. Australia is a table-land surrounded by a mountain arc of which only the ruins are visible as New Zealand and New Caledonia; these fragments appear under peculiar conditions, and the direction of the arc is different from that of those previously considered. In eastern China, Richthofen has made us acquainted with extensive table-lands; on the other hand the course of the islands off the coast indicates new syntactic ranges extending from Formosa through the Liu-Kiu islands to Kiushiu, then through

[1] O. Feistmantel, On the Occurrence of the Cretaceous Genus Omphalia near Namcho Lake, about 75 miles north of Lhassa; Rec. Geol. Surv. Ind., 1877, X, pp. 21-25.

[2] G. Kreitner, Im fernen Osten; Reisen des Grafen B. Széchényi in Indien, Japan, China, Tibet u. Burma, 8vo, Wien, 1881, pl. iii.

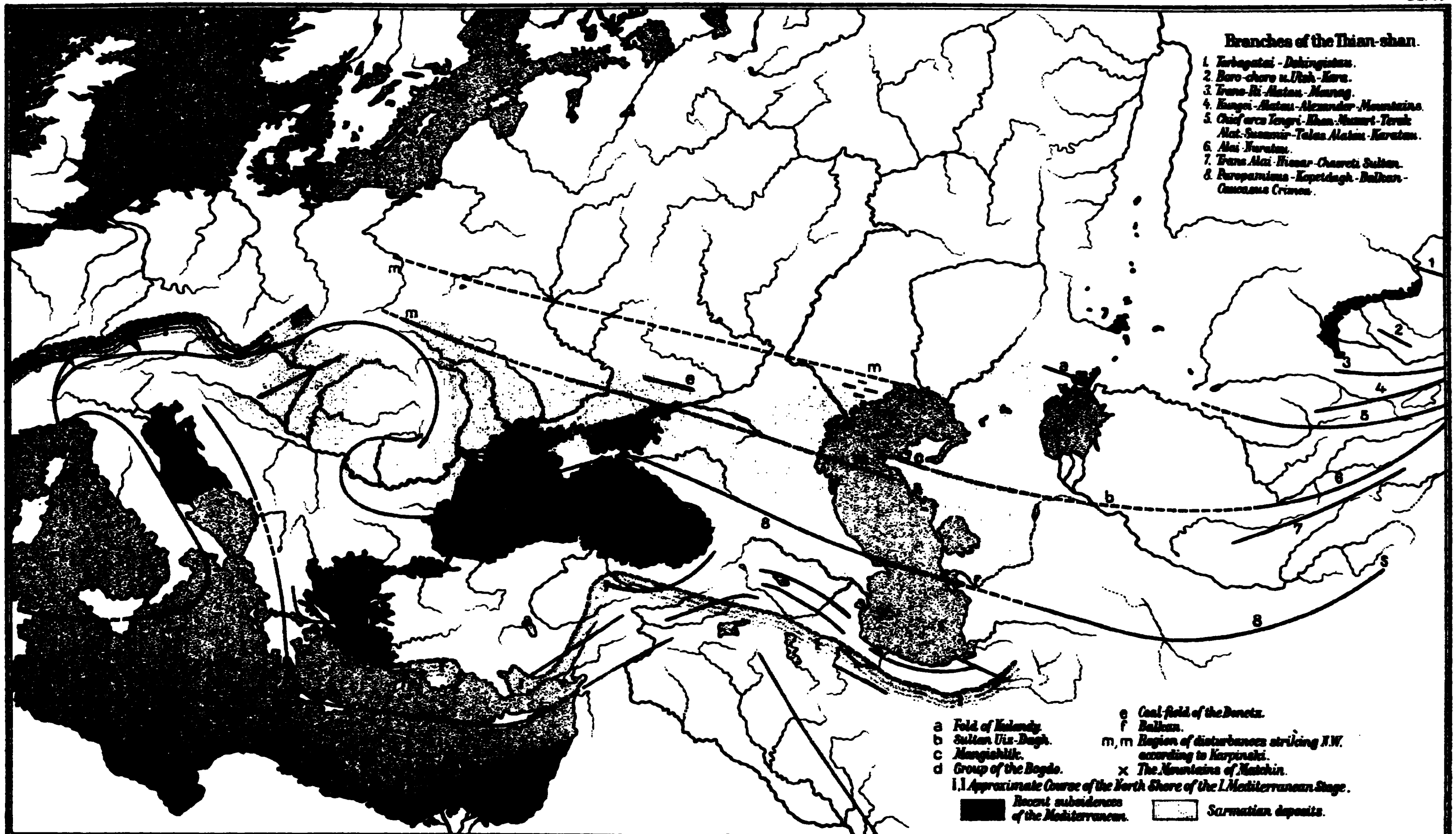
[3] Ratte, Note sur l'Indo-Chine, Bull. Soc. géol. de Fr., 1876, 3e sér., IV, pp. 509-521; Petiton, Carte géol. du Cochin-Chine, op. cit., 1883, 3e sér., XI, pl. viii; E. Fuchs, Comptes rend., 10 July, 1882, p. 107, and Zeiller, tom. cit., 24 July, 1882, p. 194; Zeiller, Flore du Tonking, Bull. Soc. géol. de Fr., 1883, 3e sér., XI, p. 436 et seq. et passim.

Nipon to Yesso, thence through the Kuriles to Kamschatka, finally through the Aleutian islands and Alaska towards Kenai and to the syntaxis with the north-west extremity of the American mountain chains.

A series of syntactic arcs thus advances from north-west, north, and north-east towards the North Pacific Ocean in the same way as a similar series advances towards the Indian peninsula. *A very remarkable tectonic homology exists between the table-land of India and the northern part of the Pacific Ocean*

For several reasons, however, I shall reserve a more detailed discussion of eastern Asia for a later chapter. To facilitate this task we shall precede it by a description of the best known table-land occupying a position between mountain chains, namely the Colorado Plateau in North America, and by a preliminary account of the peculiar features of the stratified succession in some other table-lands. Then it will be possible to consider the borders of the Pacific as a whole and to study the remarkable contrast they present to those of the Atlantic Ocean.

Pl. V.




**The Relation of Europe to Asia.**

(See Cap. VIII, Note 1)

# CHAPTER VIII

# THE RELATION OF THE ALPS TO THE MOUNTAINS OF ASIA[1]

The object of this chapter. Thian-shan by J. Muschketoff. Western branches of the Thian-shan. Nuru-tau, Scheich-Djeli, Mangischlik, Coal-field of the Donetz. Paropamisus, Khorassan, Kopet-dagh, Balkan, Caucasus, Crimea. Matschin. Balkans and Carpathians. Albourz, Iranian-Tauric syntaxis. Dinaric chain. Explanation of the vortical arrangement of the Alps. Ural, Pae-choi, and Timan. Summary.

We now approach the most difficult part in our comparative study of the course of great mountain chains. Two extensive regions have so far been discussed, the system of the Alps in the west and the Asiatic arcs in the east, both of which have received their form from tangential movements, but the arrangement of the trend-lines in these two regions is, in appearance at least, entirely different. The question thus arises, In what way do these two systems of trend encounter each other?

We must first consider more closely the principal latitudinal chain of the interior of Asia, the Thian-shan, and trace the course of its western ramifications towards Europe. We must then inquire whether with the termination of the Carpathians in Transylvania we have really reached the end of those lines which form part of the vortical arrangement of the Alps. Finally we must turn our attention to the south, and seek to determine whether the Iranian arc is really the most westerly of the syntactic arcs, or whether we shall meet with a further repetition of this feature in Europe.

[1] The orthography of the names of places adopted in the preceding chapter, in conformity with the English literature, on which that chapter was principally based, has been abandoned here, where Russian and German sources have been drawn upon. I admit the inconsistency arising from this method of procedure, but there was no means of avoiding it; cf. Bull. Acad. Pétersb., 1861, pp. 158–175. Further, for the sake of clearness, I have considered it necessary to call the volcanic summit of the Caucasus *Elbrus*, and the mountain range of North Iran in contradistinction *Alburs*. The little map, Pl. V, indicates in rough diagrammatic lines some of the most important trend-lines of the Asiatic-European mountain ranges. It is intended to show approximately the manner in which the earliest outlines of the Mediterranean (*I*, *I*), of the Sarmatian sea, and the latest subsidences are related to these lines. We observe the significance of the tripartite Caspian, and the position of the Sarmatian sea outside the area of the Aegean subsidence. The Ural has not been represented, in order not to interfere with the general view of the branches of the Thian-shan, already distorted by projection. The Tauric-Iranian syntaxis is indicated only by a few lines; the ranges are too much covered by volcanic formations for complete representation. [In the case of well-known place-names the translator has adopted the customary English spelling. Elbrus is modified into Elbruz, and Alburs into Albourz.]

From this analysis it will, I hope, be possible to show in what the essential nature of the Alpine arrangement consists. In conclusion the Ural, Pae-choi, and the Timan range will be discussed.

The way is long, but there exists none shorter; by this method alone can the peculiar relations of the great mountain chains of this continent be illustrated and the significance of the intervening chains, such as the Caucasus, Taurus, Balkans, and Pindus, explained.

With so vast a subject the description must be strictly confined to ascertained facts, and even of these only the most important can be discussed.

Thian-shan will serve as a starting-point, and here I retire with pleasure in favour of a specially competent authority, and insert a description of the chief features in the structure of this extensive and lofty chain, which Professor Muschketoff, who is best qualified to speak on the subject, has had the kindness to communicate to me.

*Thian-shan (by Professor J. Muschketoff)*[1]. 'Under the name Thian-shan is comprised a whole system of different mountain chains striking as a whole from west-south-west to east-north-east. This system has its origin in the desert of Gobi, near the town of Barkul, as a comparatively low narrow chain, which however stands out in sharp relief from the desolate plain around it. Towards the west it constantly increases both in height and breadth, while it splits up into several nearly parallel chains; at the same time it gives off branches in a north-westerly direction which may often be regarded as independent chains.

'Near the head waters of the Kunges, almost opposite Yuldus, the range of Eiran-Chabirgan or Boro-khoro branches off, and this, together with the Dzungarian Ala-tau, occupies the whole of the northern half of the district of Kuldja. It is connected by the Burlik-tau with the north-western Tarbatagai.

'To the west of the peak Tengri Khan (22,500 feet) branching and at the same time an increase in breadth may be observed in a still greater degree; these attain their maximum on the meridian of Kashgar, where the whole breadth of the Thian-shan amounts to not less than 300 kilometers. In this region not less than four nearly parallel chains may be distinguished, apart from some unimportant ranges: these are (1) the Trans-Ilian Ala-tau, (2) Kungei Ala-tau, (3) Terskei Ala-tau, and (4) Kokshal. The first of these, near the celebrated defile of Buam, joins the mountains of Tchu-Ili or Süek-tube, which, like the Boro-khoro, run to the north-west. It terminates at the southern end of lake Balkash.

[1] The communication here produced in full was kindly addressed to me by Prof. Muschketoff as early as 1881, not long after his return. I have lately had the pleasure of receiving further and more detailed accounts of this range, which will be found in the work on Turkestan now being passed through the press by Prof. Muschketoff. They have proved a rich source of information, and I have made use of them in some of the following passages.

'The second range, Kungei Ala-tau, bears further to the west the name of Alexander mountains, and near the town of Aulie Ata unites with the north-western chain, Kara-tau, which runs parallel to the Tchu-Ili range.

'The two last-named chains, namely Terskei Ala-tau and Kokshal, begin near the Tangri Khan and diverge from one another towards the west like the prongs of a fork: the intervening space is occupied by mountain ranges of the second rank which attain in places an extremely great height, as for example the Ak-Shjrak covered by many glaciers and the mountains of Son-kul, Baural-bash, At-bash, &c. Of the valleys which separate these chains that of the Naryn, the upper river of the Syr Darja, is distinguished by its great extent.

'The Terskei Ala-tau is continued in the Susamir-tau and terminates to the west in a whole series of parallel chains, Talaskei Ala-tau, Chotkal, and the Namangan mountains. Kokshal is continued under the names of Kurpe-tau and Suek-tau as far as the Alai chain, the connecting link between the system of Thian-shan and the Pamir.

'The Ferghana mountains, on the meridian of Suek, run in a north-westerly direction between the Alai and the chains of Namangan and Chotkal just mentioned. They form the eastern boundary of the district of Ferghana, while the Namangan and Chotkal limit it on the north and the Alai on the south. Towards the west they also run out to the north-west, like the little range of Kasj-kurt and the long Nura-tau, a branch of the Turkestan mountains, which in their turn must be regarded as a continuation of the Alai range.

'Parallel to the Alai range run the Sa-Alai (Trans-Alai), and further to the west the Hissar mountains and the mountains of Peter the Great. They all break up into a number of radially diverging ranges of trifling extent and height, which advance into the plain of Bokhara. The radially divergent western branches of the Thian-shan system lose themselves gradually in the depression of Turan.

'All these numerous ranges may be comprised in three groups: (1) those which strike east-north-east; these are by far the larger part and determine the direction of the whole system of the Thian-shan; (2) those with a north-westerly direction; they form the western branches of the principal chains; and (3) those running to the west, few in number and only occurring as ranges of the second order. Where ranges of the first group encounter those of the second, they regularly bend away from the latter, with their convex side turned to the south; at the same time the slopes facing the north are steeper than those on the south; the northern slopes present a greater development of massive rocks than the southern, which in their turn show a more regular system of folds. These relations moreover hold generally for all the chains of the Thian-shan in their whole extent, but it is at the points of union that they are most clearly displayed.

'In the composition of the mountains Palaeozoic formations, including the Carboniferous limestone, play the largest part, and next metamorphic and massive rocks; isolated deposits of younger formations occur to a slight extent in the mountain valleys and always rest unconformably on the Palaeozoic. The following have been recorded: Trias, Jurassic (rich in coal), Cretaceous, and Tertiary: the last named is represented by friable limestones, sandstone, and siliceous conglomerates.

'All these sediments, like the Eocene of Ladakh in the Himálaya, have been observed at considerable heights in the mountain valleys (in the Alai at an elevation of from 10,000–11,000 feet), but they are chiefly developed at the foot of the mountains, next the plain, and may be seen very clearly exposed in the river valleys, e.g. in the Ferghana region, in Kuldja, &c., and in the south-west of Bokhara and in Hissar, where they form whole mountain ranges. They are distributed over the entire adjoining plain, towards the west as far as the sea of Aral and the Caspian, towards the east as far as the Lob Nor; they surround the whole of the Thian-shan in a continuous girdle, and it is only at the extreme eastern end, near the town of Barkul, that they have not yet been recorded; but this locality is still unexplored by geologists.

'These sediments play an important part in central Asia, since the friable Tertiary sandstones furnish material for the shifting sand, which is spread by the wind over vast areas and gives to the deserts their peculiar character; and some interest attaches to the fact that it was the combustion of the thick beds of Jurassic coal which led Humboldt to assert the existence of active volcanos in central Asia, an error which has unfortunately survived to the present day. At every spot where the great naturalist, trusting to the reports furnished by the Chinese, has indicated the existence of volcanos or solfataras, burning Jurassic coal-measures have been observed, as for instance in Kuldja, Urumtchi, Turfan, Kutchi, &c., i.e. both to the north and south of the Thian-shan.

'As regards the massive rocks, in the Thian-shan they are of most various kinds and occur between the metamorphic and Palaeozoic regions, but with an extension and development which varies in the different chains. Thus, granite, granitite, syenite, granite porphyry, orthoclase porphyry, felsite, gabbro, &c., predominate in the massive chains running to the north-east; diabase, melaphyre, dolerite, teschenite, porphyrite, &c., in those running to the north-west; diorite, gneiss, &c., in those directed from west to east. The crystalline rocks prevail almost everywhere on the steep and concave slopes facing the north; thus, on the north slope of the Trans-Ilian mountains, felsite porphyry, orthoclase porphyry, spherulitic and quartz porphyries occur; the same is the case in the Tchu-Ili mountains; syenite and diorite appear on the north slope of the Terskei Ala-tau; melaphyre and diabase on the north slope of the Aigjr-tau;

melaphyre on the north-east slope of the Kara-tau; augite porphyry on the north-west slope of the Talas Ala-tau mountains and on the north slope of the Sonkul mountains; diabase on the north-east slope, augite porphyry and andesite on the north slope of the Kara-teke and near Suek; further to the south on the river Toyun, basalts occur.

'With regard to the latter extrusions I may observe that although the rocks which appear to the south of lake Tchatyr-kul are undoubtedly of volcanic origin, yet this fact in no way affects what has been said above as to Humboldt's views, since these rocks were not erupted in recent times, but by ancient volcanos of Tertiary age; the same is true of the dolerite of the Eiren Chabirgan, of the Karakasyk in the Alai mountains, the teschenite of the Kasj-kurt, &c.

'The occurrence of volcanic rocks to the south of the Thian-shan seems to contradict the general statements which have been made as to the distribution of the massive rocks; but this is only in appearance, for these rocks occur on the north slope of the Kokshal or Suek-tau and on its western prolongation, that is, under the same conditions as all the other massive rocks in the Thian-shan. In the same way teschenite appears on the north slope of the Kasj-kurt; gabbro, melaphyre, and granite on the north slope of the Alai mountains; so that everywhere in the Thian-shan the same relations prevail, save for a few exceptions in ranges of no importance.

'As regards the age of the Thian-shan mountains, the massive north-east chains are older than the others, but the epoch of their formation can scarcely be more remote than the Trias; the more recent north-west chains probably arose after the close of the Tertiary period, simultaneously with an important increase of the already existing elevations, since, as we have said above, Tertiary deposits appear at very considerable heights. It was thus not till after the Tertiary period that the Thian-shan received its final form, and certain indications lead us to suppose that elevation is still proceeding at the present day; these indications are, however, only indirect and open to doubt.

'In conclusion it follows from the account we have now given that the Thian-shan stand in reversed relations to the Alps. In the latter the trend of the chains is convex to the north, in the Thian-shan to the south; there the southern slopes are steep, here the northern; there massive rocks prevail on the southern slopes, here on the northern. But the connexion which has been shown to exist between these various phenomena in the Alps, Carpathians, and other chains is no less manifest in the Thian-shan; which likewise present a great uniformity in the strike of the folds and the direction of curvature. The massive rocks have played a purely passive part in the formation of the Thian-shan; a line joining the various places of intrusion coincides in no way with the direction of the crest. As

regards this point numerous observations have been made in the Thian-shan analogous to those made by yourself and Professor Heim in the Alps.'—

Thus far Muschketoff's description. It leads above all to the important result, that the tangential movement of the syntactic Indian arcs, having on the whole a direction to the south, is also manifested in the long ranges of the Thian-shan, and that in the whole interior of Asia this movement to the south is the dominant factor; to this, indeed, the continent owes its form.

Of the branches of the Thian-shan enumerated as running to the north-west, two do not come into consideration here, since they do not reach Europe; these are Boro-khoro with the Tarbagatai, and the Trans-Ilian Ala-tau with Suek-tube. It is open to inquiry whether the isolated folds, which appear in the peninsula of Kulandy, on the north-west shore of the Aral, and the mountains of the Astrakan steppe, which run to the north-west, such as Tschaptschatschi, for example, and the group of the Great and Little Bogdo, are not perhaps prolongations of the Kara-tau, which proceeds from the Alexander mountains in a north-westerly direction; but these chains are separated by such a great distance from one another that it is difficult to decide this question.

On the other hand the continuation to the north-west of that branch of the Thian-shan which succeeds on the south is particularly clear.

*Nura-tau—Mangishlak.* Nura-tau, coming from the Alai, proceeds as a high snow-covered range with a north-westerly trend towards the steppe of Kizil-kum and separates the Syr Darja from the Amu Darja. Its further continuation is formed by the range of *Sheich Djeli* or Sultan-Ujzdagh, 60 kilometers in length, which reaches the Amu Darja below Khiva. It consists, according to Barbot, of granite, gneiss, talc schist, chlorite schist, as well as calc-schist with epidote (pistazite) and marble; its strike is north-west (hor. 6–7), its dip very variable, frequently vertical, and the Cretaceous beds extend unconformably up to the summit of the chain [1].

Remains of the Cretaceous spared by erosion rise from the delta of the Amu Darja; they are the outposts as it were of the Ust-Urt. On the west side of the great table-land, however, a prolongation of the mountains trending north-west makes its appearance. This forms the peninsula of *Mangishlak.* It is a regular anticlinal, striking north-west; the middle region, consisting of unfossiliferous quartzite and clay slate, forms the Kara-tau; in the valleys to the north and south the Jurassic formation and the Cenomanian horizon of the phosphorites crop out; the two Ak-tau (i. e. White mountains) to the north and south belong to the upper Cretaceous. On the summit of the Kara-tau, Barbot observed a horizontal

[1] N. Barbot de Marny, Letter in Neues Jahrb. f. Min., 1875, pp. 858–861. The calc-pistazite schist of the Sheich Djeli is described by Inostranzeff in the Verh. russ. Min. Gesellsch., 1874, 2. Folge, IX, pp. 88–92.

patch of Sarmatian [1]. This fold would thus be more recent than the Sheich Djeli.

In connexion with the Mangishlak, Karpinsky distinguished a broad zone in south Russia, in which dislocations occur in a somewhat north-west or west-north-west direction [2] (*m*, *m*, Pl. V). The first and most striking example is the folding of the Carboniferous deposits of the Donetz, which lies precisely in the line of continuation of the Kara-tau on Mangishlak. The strike for a great distance is to the north-west; borings show that this coal basin proceeds as far as the river Orel. Other cases of dislocation with the same strike are known in the governments of Kharkov and Ekaterinoslav, at Isatshki (district Lubny, in the government of Poltava), and, according to Feofilaktoff, at Kanef on the Dnjepr (government of Kiev); indeed, this observer includes in the same zone of parallel disturbances the *Sandomir mountains* in Poland, which lie in folds striking to the north-west, but are situated several hundred kilometers distant from Kanef, the most westerly of the points mentioned.

Whether this assumed connexion should prove to be well grounded or not, it is at least certain that from the Alai through the Nura-tau, Sheich Djeli, Mangishlak, and the coal-field of the Donetz, a number of subsidiary disturbances take the same direction. Cretaceous beds also take part in these disturbances, and Karpinsky justly emphasizes the fact that although they occur in the immediate neighbourhood, yet the Silurian on the Dnjestr and the Devonian in Orel and Voronezh remain horizontal. Generally speaking, however, we may distinguish a group of very ancient disturbances striking north and north-east in the Archaean complex—these have been abraded down to one level and subsequently covered by horizontal Palaeozoic sediments; next a group running north-west, parallel to the Caucasus to which Mangishlak belongs—these are of various age, but certainly of common origin; finally a group, perhaps still more recent, represented by the hills of Ergeni, which run almost meridionally or north-north-east.

It is this second group which corresponds to the great Asiatic ranges.

*Paropamisus—Caucasus.* The gentle curve of the Paropamisus is continued in a straight line to the north-west through the mountain ranges of Sarakhs, the Kopet-dagh, and the Kuren-dagh. The latter range is 2,000–3,000 feet high; Sievers, who crossed it near the fortress of Kizil-Arvat, found Sarmatian foot-hills and, at the summit of the pass, light grey

[1] Barbot, loc. cit., p. 859; also G. v. Helmersen, Notiz über die Berge Aktau und Kara-tau auf der Halbinsel Mangyshlak, Bull. Acad. Pétersb., 1870, XIV, pp. 529-535; E. v. Eichwald, Geogn.-pal. Bemerkungen über die Halbinsel Mangishlak und die Aleut. Inseln, 8vo, Petersb., 1871.

[2] A. Karpinsky, Bemerkungen über den Charakter der Dislocationen der Felsarten in der S. Hälfte des europäischen Russland; Gornoi Journ., 1883, pp. 434-445 and plate. The author includes the group of the Bogdo mountains in this zone.

limestone belonging to the upper Cretaceous; no older rocks are so far known[1].

The Kuren-dagh is immediately followed by the Little Balkan, and then at a short distance by the Great Balkan and the group of mountains on the bay of Krasnovodsk.

According to Koschkul's investigations the mountains of the bay of Krasnovodsk form, together with the Great Balkan, a single anticlinal, striking to the west-north-west, exactly in the direction of the Caucasus; its south limb is for the most part faulted down. The *Great Balkan*, on the western border of which the Dagh-dirim-burun rises 5,650 feet above the Caspian, is the eastern part of the south limb left standing; its beds dip to the south. The middle of the saddle lies beneath the bay of Krasnovodsk and the bay of Balkan, and is continued on land in the direction of the fortress of Tash-arvat-kala, at the north-west foot of the Great Balkan. The deepest visible rocks form the low foot-hills, trending from east to west, in the neighbourhood of Krasnovodsk; Koschkul describes them as granite and greenstone; the latter is regarded by Dölter and Tietze as an older porphyrite. The ranges which succeed to the north, the Kuba-dagh, continued by the island Dagh-ada, the long range of Kjurre and its eastern prolongation, the Kosha-seira, form the north limb of the anticlinal and the beds dip to the north. In the Kuba-dagh gypsiferous beds appear; Kjurre consists of clay-slate and glauconitic sandstone, the same probably as that which Sievers describes as Cretaceous in the Kosha-seira[2].

This small group of mountains is remarkable in two respects; in the first place it forms, as is clearly indicated by a submarine ridge, the continuation of the Caucasus, and thus connects it with the long ranges which run to the Paropamisus; and next, as Karelin showed many years ago, the ancient mouth of the Oxus lies in its neighbourhood. The mighty river flowed between the Great and Little Balkan, and then appears to have divided into two arms, at the head of the great delta, which at present forms the flat peninsula of Dardscha. This has been deposited upon the down-thrown southern limb of the anticlinal, that is, over the subterranean continuation of the Great Balkan.

[1] G. Sievers, Die russ. militär. Expedition nach dem alten Oxus-Bette, dem Kjurjandagh-Gebirge u. d. Atrek-Thale, August to December, 1872; Petermann's geogr. Mitth., 1873, XIX, pp. 287–292. For the Balkans I must refer the reader once for all to the beautiful map, pl. xv, which accompanies this treatise.

[2] F. v. Koschkul, Report on the Geological Investigations made between Nov. 1869 and March 1870 in the neighbourhood of the Bay of Krasnovodsk and the Island of Tcheleken, Iswest. geogr. Ges. 1870, VI, pp. 181–213, plate (in Russian); E. Tietze, Ueber einen kurzen Ausflug nach Krasnowodsk im W. Turkestan, Jahrb. geol. Reichsanst., 1877, XXVII, pp. 1–6; A. Konschin, Description of the Ozokerite and Petroleum Localities of the Trans-Caspian region, Gornoi Journ., 1883, Pt. 1, pp. 134–150, plate (in Russian).

To the south of the dry bed of the Oxus, and extending as far as the sea-coast and the island of Tcheleken, as well as further towards the south, lie the deposits of this region which produce petroleum.—

We have now reached the *Caucasus*, and the question arises whether in this mighty range the tangential force is directed to the south, as in the chains of central Asia of which it appears to be the continuation. The answer is that the Caucasus presents a very peculiar structure, very different from the simpler constitution of other chains. We are indebted for our knowledge of it to Abich's prolonged and comprehensive investigations [1]. It is indispensable that we should enter into his statements in some detail, since they are of great importance for the study of mountain formation in general; we shall then see that the conception of the Caucasus as a unilateral chain simply moved to the north and north-east, which I at one time believed might be deduced from Favre's investigation of these mountains, is indeed justified in a certain sense, but fails to take into account the most characteristic feature of its structure [2].

In two regions ancient crystalline rocks, principally granitic, occur, which may be regarded as the Archaean foundation. The first of these belongs to the great chief crest of the Caucasus and extends from the source of the Kuban to that of the Terek; this is the high snow-covered region between the Elbruz and Kasbek. The second region of Archaean rocks lies far below at the southern foot, and there forms the watershed between the Pontus and the Caspian. *Its strike is directed to the north-east and is thus completely different from that of the Caucasus*; the accompanying sedimentary beds correspond in character to those of Armenia; on the eastern side middle Cretaceous beds lie transgressively on the Archaean. These are the *Meskian mountains*. We regard them as a mountain system alien to the Caucasus, and shall return to them later on.—

Having thus separated off the Meskian mountains, let us attempt to approach the Caucasus from the north. We first encounter the Sarmatian table-land of Stavrapol, which rises to a height of 2,500 feet, then the district of Piatigorsk, rich in mineral springs and including the isolated eruptive mass of the Besh-tau; further to the south-east, between the Terek near Mosdok, and Vladikavkas, rise two long ridges, which run parallel to the Caucasus, and, according to Koschkul's sections, have been produced by folding of the Sarmatian [3].—

[1] The principal work on this subject is by H. Abich, Vergleich. geöl. Grundzüge der kaukasisch-armenischen und nordpersischen Gebirge, Prodromus einer Geologie der kaukasischen Länder; Mém. Ac. Pétersb., 1858, 6e sér., VII, pp. 361–365, and plate.

[2] E. Favre, Recherches géol. dans la partie centrale de la chaîne du Caucase, 4to, Genève, 1875, 117 pp., map and section; E. Suess, Entstehung d. Alpen, p. 47; cf. above, p. 137.

[3] F. Koschkul, in the Gornoi Journ., 1879, c, pl. ix.

The first zone of the Caucasus consists of a thick conformable series which includes sediments ranging from the Lias to the upper Cretaceous, and in places even some superposed Flysch. As a general rule this zone is normally inclined to the north-east. In the meridian of the Elbruz the dip is slight and very regular; even at a distance of 60 kilometers north of the crest of the mountains erosion has laid bare the Archaean foundation beneath; the surface of this has also a gentle inclination to the north, and it may be regarded as the floor on which the Lias sediments were originally laid down. Towards Vladikavkas the zone narrows away, but further to the south-east in Daghestan its breadth increases; here it is folded in parallel saddles and troughs, which recall in many respects the structure of the Jura. The whole folded zone ascends towards the south with constantly increasing height; looking south also are the long successive scarps formed by the steep basset edges of the various subdivisions of the stratified series. Isolated table mountains rise in front of these escarpments to a height of 8,000 feet, and finally, in the tabular zone of the Shach-dagh, even to 12,041 feet. It is here that the Sarmatian deposits, which invade the valleys excavated in the older sediments, have been carried up to a level of 7,170 feet above the sea.

From the heights of the Shach-dagh the south-eastern Caucasus descends southwards in mighty step-faults to the basin of the Kura. Here lies the great seismic region of subsidence, extending from Shemaka and Nuka to Elisabethpol and Shusha. Here also this single zone, inclined and folded to the north and fractured to the south, forms the whole Caucasus. No Archaean rocks are visible; the folding of Daghestan has evidently been produced by lateral pressure directed to the north[1].

Thus far in the whole of the south-east the conception of a chain folded to the north and thrown down on the south corresponds to the facts. It is otherwise in the north-west.

The Archaean rocks, which form the crest of the high mountains between Elbruz and Kasbek, descend to the south in precipitous walls crowned with snow; below them a thick belt of ancient schists crops out, and east of the Adai-choch (12,250 feet) even overtops the granite, which retreats to the north side of the mountains. This belt of ancient schist *dips to the north-east beneath the granite, so that the whole mass of this part of the Caucasus reveals itself as a colossal fold overturned to the south-west.*

The masses of schist on the south side present the same dip to the north-east as the Jurassic and Cretaceous beds of the north slopes, and

[1] H. Abich, Verzeichniss einer Sammlung von Versteinerungen von Daghestan, mit Erläuterungen, Zeitschr. deutsch. geol. Ges., 1851, III, pp. 15–48, and Sur la structure et la géologie du Daghestan, Mém. Acad. Pétersb., 1862, 7e sér., IV, pp. 10, 12.

Abich is therefore right when he says '*the fundamental law of the Caucasus is isoclinal dip to north and north-east*[1].'

The schists when contiguous to the granite are mica-schist and chlorite schist; the main mass is clay slate, which Favre regards as Palaeozoic, while Abich emphasizes the entire absence of fossils and appears inclined to assign it in great part to the coal-bearing Lias. Further south, towards the upper Ingur, the inversion of the schist gives place to fan structure and finally to sharp folding, which certainly already involves the Lias. This is followed by a steep fault on the upper Rion, and a new series, beginning with the Sarmatian stage and dipping to the north, forms the orographic connexion with the Meskians, but under complex conditions into which I cannot undertake to enter. This northwards dipping series, however, no longer presents the Caucasian character, but the southern facies of the Tauric-Armenian deposits, which are distinguished by their resemblance to those of the eastern Alps.

Thus the Caucasus consists of two parts of different character, which, however, are structurally distinguished only by the fact that in the north-west part the basis of the whole northern series of Jurassic and Cretaceous beds remains exposed to view as a fold overturned to the south, while in the south-east part this basis has subsided beneath the plain of Kur.

Here and there eruptive rocks have been extruded along the fractures. The principal chain is crowned by the two mighty masses of the Elbruz (18,453 feet) and the Kasbek (16,553 feet). Many years ago, when the researches of geologists were influenced by conceptions of a very different nature, Abich perceived that the great volcanos of Armenia stand on areas of subsidence, and he clearly recognized that the Elbruz and Kasbek, although placed on the crest of the Caucasus, were yet formed subsequently to the elevation of the mountains, and even after the excavation of a part of the valleys. So clearly did this observer perceive even at that early date the sequence of events, that he was able to show how great masses of lava had poured out into a valley eroded in the slate, had consolidated there, and how then by gradual destruction of its walls this valley of the schist zone was transformed into the volcanic table-land of Keli.

What we have said with regard to the volcanos of Sumatra is, however, also true of these volcanos which surmount the Caucasus; it is the chain itself which breaks up, and here this is the less surprising since in the south-east so large a part of this same chain has already actually disappeared by fracture and subsidence.

So, too, on the other side of the Caspian we have seen the monoclinal of

[1] H. Abich, Vergleichende geol. Grundzüge, p. 459. Favre explains the inversion as the result of a great subsidence to the south, loc. cit., p. 71.

Krasnovodsk inclined to the north-east under the same conditions as the much greater series of the Daghestan.—

The north-western part of the Caucasus sinks near Anapa as a band of Flysch beneath the Black sea, having previously given off a ridge to the north-north-west, the extreme and lowest part of which forms the south side of the Liman of Temrjuk on the sea of Azov.

A great number of Sarmatian folds now appear, running across the peninsulas of Taman and of Kertch; for our knowledge of these we are also indebted to Abich, and they afford material for several conclusions of a general nature [1].

The northern folds run from east to west; two of them cross the strait and proceed north and south of Kertch, so that this town is situated on the intervening synclinal. Towards the south however, and beginning at the Liman of the Kuban on Taman, these folds gradually bend to the south-west; to these also belongs the mountain of Opuk (the ancient Cimmerium), 570 feet high, on the south coast of the peninsula of Kertch.

The gradually increasing importance of the direction to the south-west I interpret either as the first indication of a new chain or as a bending of the Caucasus itself; it is the direction of the mountains of the Crimea. According to Abich's sections even the Pontic Cardium beds of Kertch appear to have taken part in this folding.

In either case the folds of Taman and Kertch form the connexion between the Caucasus and the Crimea.

In the south-east of the *Crimea* a mountain segment rises to a height of about 1,500 meters; its strike is to the south-west and the general dip to north-west. The oldest rocks belong to the Lias, which forms the south-east coast of the peninsula and, like the Lias of the Caucasus, contains numerous remains of terrestrial plants. This zone might at once be recognized as the continuation of the northern zone of the Caucasus, were it not for two essential points of difference observed by E. Favre. In the northern Caucasus, as far as Daghestan, all the sedimentary formations from the Lias upwards succeed one another in complete concordance; in the Crimea, on the contrary, the Lias is strongly folded and dips to the north; the Jurassic limestones rest upon it in great broken fragments, and a conformable series does not begin till the Neocomian. The Neocomian has thus been preceded by a great disturbance, which did not affect the Caucasus. Furthermore, in the Crimea the Cretaceous is succeeded by the Nummulitic limestone, and this is absent in the northern Caucasus.

For these reasons Favre compares the Crimea, not with the northern, but with the southern Caucasus, i.e. the Meskian mountains, which we

[1] H. Abich, Einleitende Grundzüge der Geologie der Halbinseln Kertsch und Taman, Mém. Acad. Pétersb., 1865, 7e sér., IX, pp. 1–80, plate; and by the same, Karten und Profile zur Geologie der Halbinseln Kertsch und Taman, Tiflis, 1866.

however have recognized as a chain running to the south-west and alien to the Caucasus. Favre at the same time emphasizes the original connexion between the Balkan and the mountain fragment of the Crimea. In support of this view, which is also adopted by Lagorio, it is stated that the zone of fracture along which, according to Hochstetter, the Balkan from Pirot to cape Emineh sinks to the south would, if continued, meet the south-east coast of the Crimea, and that beneath the Black sea, from cape Emineh as far as cape Saritsch, a rapid descent, from depths of 70–80 meters to 1,000–1,800 meters, occurs within a comparatively trifling distance. The subsidence is assigned to the Miocene period [1].

*The mountains of Matchin.* A transgression of the upper Jurassic extends over the Russian Platform; Neocomian and Gault are absent, and middle and upper Cretaceous extend horizontally over the flat-lying Jurassic. The same succession appears in that part of the Russian Platform in Galicia which is exposed in the neighbourhood of the Carpathians by deep river channels. The middle and upper Cretaceous rest on the horizontal red sandstone, but in some places in the valleys of the Dnjestr and the Zlota Lipa calcareous sediments containing many fossils of the Kimmeridge and Portland stages of north Germany and France lie between the Cenomanian and Devonian. The character of these Jurassic stages is completely different from that of the Jurassic near Moscow, and it is only with the highest parts of the latter that they can be compared as to age, but the mode of occurrence is the same. This phenomenon is repeated in one part of the Dobrudja, viz. on the Danube between Rássova and Hirsova, on the sea-coast in the neighbourhood of Kustendje and in the intervening districts. Beds of upper Jurassic with Nerinaea, Pteroceras, and Diceras crop out on the right bank of the Danube in horizontally stratified reefs of considerable size; they are overlaid by the middle and upper Cretaceous. This Jurassic limestone plateau does not, however, rest here on horizontally bedded Palaeozoic strata, but against the remains of the pre-Jurassic folded chain, the north-western end of which causes the sharp bend of the Danube above its delta opposite Braila and Galatz. This fragment has been described by Spratt and Peters [2].

At Kara-kioi, north of Kustendje, we meet, coming from the south,

[1] E. Favre, Étude stratigr. de la partie S. O. de la Crimée, 4to, Genève, 1877, 71 pp., map; A. Lagorio, Vergleichende petrogr. Studien über die massigen Gesteine der Krym, 8vo, Dorpat, 1880, in particular pp. 16-26; for the connexion with the Balkan, T. Spratt, Comparison of the Geological Features of Bulgaria and the Crimea (in Geology of Varna), Quart. Journ. Geol. Soc., 1857, XIII, pp. 79, 80.

[2] T. Spratt, On the Fresh-water Deposits of Bessarabia, Moldavia, Wallachia, and Bulgaria, Quart. Journ. Geol. Soc., 1860, XVI, in particular pp. 290-292; K. F. Peters, Grundlinien zur Geographie und Geologie der Dobrudscha, Denkschr. Akad. Wiss. Wien, 1867, XXVII, pp. 3-64 and 145-207, map; further by the same, Die Donau und ihr Gebiet, 8vo, 1876, pp. 334-342.

the first traces of steeply dipping green schist, which, extending from here towards the north-west as far as Petcheniaga on the Danube, crops out in ridges of considerable size, frequently accompanied by diabase tuff. Along the sea-coast the strike of the green schist is west-north-west, becoming north-west next the Danube. Towards Babadagh the Cretaceous extends over the schist and proceeds to the south-east as far as the great Rasim lagoon. A second much shorter rocky range, distinguished by rugged outlines and composed of gneiss and granite, rises near Matchin, east of Braila, with a north-westerly trend: to this belongs the isolated mountain of Garbina, south-east of Galatz.

Finally a third zone lies to the north of the gneiss chain of Matchin and the Cretaceous of Babadagh, and occupies, although frequently concealed for long distances by recent sediments, the whole space as far as the Danube near Isaktcha and Tultcha and Dunavez in the delta. Here Verrucano, various stages of the Trias, red Lias, and traces of Jurassic appear. It is the Verrucano which forms the 'Rock' on the Danube near Tultcha; and Serpent island, far out in the Black sea, also consists, according to Spratt, of an ancient rock [1]. Popin island in the Rasim lagoon is composed of Muschelkalk; and the Trias, by its great eruptive masses of melaphyre and the occurrence of *Halobia Lommeli*, Arcestes, &c., recalls the southern Alps. The strike is west-north-west.

This range is a completely unsolved problem. While the succession of the rocks points as we have said to the Alps, the strike of the green schist north of Kustendje, as well as of the Trias near Tultcha, is that of the Caucasus. The gneiss of Matchin strikes a little more to the north. The direction is thus in sharp contrast to that of the next adjacent part of the Carpathians. In like manner the horizontal position of the upper Jurassic on the green schist is opposed to all that is known concerning the comparatively recent age of the movements which have given rise to the Carpathians.

The range of Matchin is thus a fragment of a once larger folded chain, having the trend of the Caucasus or one slightly more to the north, the stratified sequence of the Alps, and an origin which is anterior in time to the upper Jurassic.

*Carpathians and Balkans.* It has only lately been possible, thanks to the efforts of our colleagues in Hungary, Roumania, and Servia, supplemented by the results of earlier researches in Austria and valuable local

[1] T. Spratt, Remarks on Serpent Island, Journ. Geogr. Soc. Lond., 1857, XXVII, pp. 220–224. As regards the nature of the rock of which this island is formed I must confess that I have not been able to arrive at a definite opinion. Spratt says it appears to be a spur of the schist mass of the Dobrudja, consisting of siliceous beds with great crystals of quartz, sometimes passing into red jasper, the beds being separated by schistose layers and inclined 10°–20° to the east. The island is 130 feet high.

investigations in Transylvania, to follow the numerous chains connected with the arc of the Carpathians, as well as the intermediary links between these and the Balkans. We arrive at the conception of a peculiar tectonic phenomenon, which nowhere else in the earth's crust, as at present known to us, is displayed in such clearness or exhibited on so grand a scale; but here again it is indispensable to enter a little further into detail.

We have shown that according to the observations of Loczy there exists within the arc of the Carpathians, and indeed within the bend of the river Maros in Transylvania, a fragment of an independent arc, which has been thrust to the east, south-east, and south (pp. 219, 232). We will now first attempt to trace the conditions under which the outer curve is continued, as far as our present knowledge of the structure of the Roumanian slope permits. For the south-east of Transylvania we have a series of excellent descriptions by Meschendörfer, Hauer and Stache, and Herbich; with regard to the south I shall follow principally the data of Stefanescu[1].

The Carpathians present in the east the normal structure of a simple chain folded towards the exterior and collapsed on the interior. A great arc-shaped band of ancient rocks, chiefly mica-schist, extends from the sources of the Theiss through the south of Bukowina, a part of Moldavia, and the north-east of Transylvania, and terminates in the Csik, near the head waters of the Alt. This range is 230 kilometers long; it strikes in its northern part to the south-east, and then bends more and more to the south-south-east. In its southern part in Transylvania there rises on the western inner border the isolated mass of the Piritske near Ditró, formed of elaeolite syenite, and this is followed on the west by the long trachyte range of Hargitta, which runs parallel to the band of schists. In the east, resting against the ancient rocks, is a short rugged range of Trias and Jurassic deposits; it includes the Nagy Hagymás, and is followed in turn to the east by the broad wooded zone of repeatedly folded Flysch, which sinks gently down far away into the plain of Moldavia.

Further to the south all the interior zones disappear; the Flysch, which is here chiefly Cretaceous, alone remains, accompanied by limestone of the same age. The strike passes rapidly from south-south-east to south, and finally becomes south-south-west. On the Dimbovitza, between Kimpulung and Tingovisti, the whole of this broad Cretaceous zone has vanished beneath the Roumanian plain, and is followed towards the west

[1] As the principal sources of information I may mention: J. Meschendörfer, Die Gebirgsarten im Burzenlande, Verhandl. u. Mittheil. d. siebenbürg. Vereins f. Naturwiss., 1860, XI, pp. 236-249 and 255-287; F. R. v. Hauer and G. Stache, Geologie Siebenbürgen's, 8vo, 1863, map; F. Herbich, Das Széklerland, 8vo, 1878, map (also Mitth. k. ungar. geol. Anstalt, V, Heft 2); Stefanescu's observations in the Annuar. Biur. geol. Bucuresci, 1884, I, in particular pp. 17, 18 and 47-63.

by patches of Eocene only, of which we shall speak later. Meanwhile fresh traces of the underlying beds crop out in the west. Outcrops of Jurassic limestone, striking south-west, form the neighbourhood of Kronstadt; they are continued to the south-west, so that the pass of Tömös coincides for a certain distance with the eastern boundary between them and the Flysch zone; at the same time they increase in importance. The mighty mass of the Bucsecs, which separates the northern approaches of the Tömös and Törzburg passes, is chiefly Jurassic; another part belongs to a great mass of conglomerate of unknown age. Over La Strunga the Jurassic limestone is continued towards Roumania, but at the same time the rocks below it crop out. Mica-schist, striking to the south-west, forms in the north a narrow band at the foot of the high Jurassic mountains, but becomes broader in Roumania, and according to Stefanescu composes, along with hornblende schist, the mass of *Monte Leota*; towards the south-west it again disappears, as does the Jurassic limestone.

To the west of the range of Monte Leota, a zone of Jurassic limestone and Cretaceous beds again appears; its most notable feature is the precipitous mass of the Königsberg. This zone rests against the eastern border of the Fogaras mountains, a frontier chain separating Transylvania from Roumania; it is formed of ancient rocks. Close to the north foot of the Königsberg, Herbich describes the broad outcrop of a Cretaceous series, striking north and south and dipping to the east; from the frontier chain onwards this forms all the lesser heights below the Törzburg pass.

These Jurassic and Cretaceous formations are continued northwards, but extend beyond the general contour of the mountains, and form a long independent offshoot which projects from the north-eastern end of the frontier chain to the north: this is the *Persány range.*

The Persány mountains are formed by a fold striking north and south, cut through transversely by the river Alt; the Trias, and in its southern part even the mica-schist, is visible beneath the Jurassic. Herbich has shown that the Mesozoic deposits on the eastern border of the frontier mountains are continued into the fold of the Persány mountains; but in this case we must regard the outcrop of the ancient basement beds of the Persány mountains simply as the continuation of the frontier chain itself, sharply bent to the north. That this view is correct we shall see directly from the structure of the frontier mountains.

For the present, however, we recognize the following facts. The great band of mica-schist in the Moldavian arc has disappeared in the Csiks. Its outer zone of Trias and Jurassic disappeared still earlier. The great Carpathian Flysch zone has turned completely round to the south-south-west or south-west, and has vanished beneath the surface before reaching the Dimbovitza. A Jurassic range, and within this, the range of ancient schists of Monte Leota, between the pass of Tömös and that of Törzburg,

have appeared within the Flysch zone striking south-south-west or south-west, and have also disappeared to the south-south-west. Then west of these the Jurassic range of the Königsberg has appeared together with the Persány mountains and has also vanished towards the south-south-west; the outcrops of mica-schist in this range, however, seem to be continued in the north-east corner of the frontier range; and it is this latter which we must now consider in detail.—

The Fogaras or *Transylvanian-Roumanian* frontier range follows, if we judge by its outer form, the direction from east to west; but some time ago Herr Beila von Inkey, who has examined the structure of that part of the chain which lies to the west of the pass of the Red Tower, i. e. west of the transverse valley of the Alt, was kind enough to direct my attention to the remarkable fact that this range consists of several folds, which diverge from one another towards the west [1].

The excellent representation given by Primics of that part of the range included between the Dimbovitza and the river Alt also shows clearly how little the structure coincides with the outer form.

According to Hauer and Stache the strike in the eastern part of the range is north-east to south-west, and gneiss here enters largely into its constitution [2]. Somewhat further to the south-west, but in the same line of strike, on the Papusa, in the upper bend of the Dimbovitza, west of the Mesozoic mass of the Königsberg, and nearly midway across the chain, there begins, according to Primics, a long band of gneiss, which, striking to the south-west, traverses the range obliquely. Far to the east of the Alt it reaches the southern border, which it then forms, and flanked by Eocene, continues for a long stretch beyond the river (*Gn*, Fig. 48).

At the same time there appear in the north of the chain a number of bands of schistose limestone and marble with tremolite, also rocks containing staurotide and garnet, and amphibole schists, which form the axis of the mountains, but do not follow the strike of the gneissic band.

Primics' map shows that in the north-east these bands, which recall so strongly certain rocks of the St. Gotthard mass, bend sharply round to the north, so that they return in fact to the direction of the Persánys, while on the west they follow a westerly direction, and thus in the transverse valley of the Alt are already far removed from the band of gneiss [3].

[1] This important observation has since been published by B. v. Inkey, Geo-tektonische Skizze der W. Hälfte des ungarisch-rumänischen Grenzgebirges, Földt. Közl., 1884, XIV, pp. 116–121.

[2] Hauer and Stache, op. cit., pp. 264, 265.

[3] G. Primics, Die geol. Verhältnisse der Fogarascher Alpen und des benachbarten rumänischen Gebirges, Mittheil. aus d. Jahrb. d. k. ungar. geol. Anstalt, 1884, VI, pp. 283–315, map; also S. Stefanescu, Mem. rel. la Geol. Judet. Argesiu, Ann. Biur. geol. Bucuresci, 1884, No. 2, pp. 115–147.

At the bottom of the transverse valley, near the confluence of the Lotru with the Alt, a large patch of Flysch appears as the wedged-in core of a synclinal, but it is probably only a remnant of an ancient mantle of Eocene, traces of which are known on the northern border, and in yet stronger development on the southern border, where they form isolated hills nearly as far as the river Schyl, east of Tirgu-Jiuliu[1].

We now approach the mountains on the right bank of the river Alt and follow the observations of Inkey.

The northern ridge, composed to a great extent of limestone, curves to the north-west, loses its orographic importance, and forms the outer

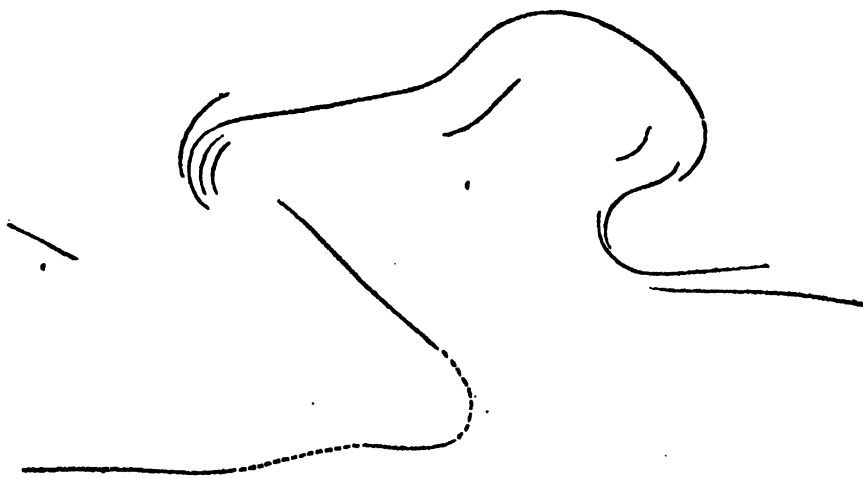


FIG. 47. *Diagram of the trend-lines of the Carpathians and the Balkans.*

border of the Mühlenbach mountains. We will call it the *Fogaras range.*

A strongly compressed synclinal, visible near Kineni on the Alt, now rises on the west, forms the long lofty crest of the mountains, and terminates on the river Strell.

Another group of folds, less strongly marked on the Alt, unites in the west into a single great anticlinal, which, bent on Mont Turcsino in a sharp S-shaped curve, forms the mountain of Mundra (2,520 meters), the principal mass of the Páring range. This branch, particularly towards the west, shows a tendency to swerve to the west-south-west. It is the *Mundra range.*

We have now reached the patch of Flysch on the Alt near its confluence with the Lotru, and at the same time the southern band of gneiss.

[1] On the north the fossiliferous locality Porcsesd, situated at the entrance of the Alt into the transverse valley, must be referred here; in the south S. Stefanescu has found Nummulites near Salatruca, east of the point where the Alt again emerges.

This does not form a high mountain range. Near Monte Cozia, still on the left bank of the Alt, it occurs as an arch descending steeply to the north, gently to the south; it forms the southern foot of the Párings, where, however, only the northern half of the arch is visible; the southern half having disappeared beneath the plain. We will call this the *Cozia range.*

The patches of Mesozoic limestone which now make their appearance leave no doubt as to its further course. The Mundra range, which is continued beyond the transverse valley of the Schyl in the south-westerly trending Strácza mountains, and consequently forms the south side of the valley of the Wallachian Schyl, is accompanied beyond the watershed by patches of Mesozoic; these, following the valley of the Cerna far to the south-west and south-south-west, finally strike to the south, and thus reach the neighbourhood of Orsova. Thus while the Fogaras range runs to the north-west, the Mundra range is turned from the south-west and south-south-west towards Orsova. It is succeeded by the Cozia range, which soon disappears beneath the plain.

While, however, the branches of the mountains thus tend to diverge widely from one another, Mount Retyezat inserts itself between them like a wedge, separating the upper Schyl from the bend of the Strell. Inkey regards this mountain as a substituted fold, places the point of divergence of the branches nearly on the watershed between the Wallachian Schyl and the Cerna, and observes that at the *triplex confinium* the strike begins to pass from west to west-north-west.

The significance of Inkey's observations will at once appear if we glance at Drâghicénu's geological map of north-west Wallachia [1]. The Cerna is indeed a true longitudinal valley, one of the few cases in this region in which the configuration of the ground corresponds with its structure. We have now entered that remarkable series of mountain ranges which are crossed by the Danube, between Alt-Moldova and the Iron Gate. In the course of the last few years they have formed the subject of numerous investigations by Kudernatsch, Schlönbach, Tietze, then by Hoffmann, Böckh, Halaváts, Roth, and others; but into the details of these it is not my intention to enter.

Our knowledge of their prolongation into Roumania now permits us to form a much more complete idea than was possible before of the general plan on which this remarkable series of mountain ranges is constructed. For the present we will leave the numerous volcanic phenomena of eruption and intrusion entirely out of consideration.

The series is usually known as the *Banat mountains.* It is preceded in the west by some hills of gneiss and mica-schist, which rise out of the Hungarian plain, e.g. the Lokva mountains, on the Danube between

[1] M. M. Drâghicénu, Carta geologica a Judetului Mehedinti, small fol., 1882.

Weisskirchen and Moldova, the hill range of Wershetz, the heights south of Dognácska, and others. These we do not include, but take the Banats to begin along a line running nearly in the meridian, drawn from Alibeg, east of Alt-Moldova on the Danube, northwards and somewhat

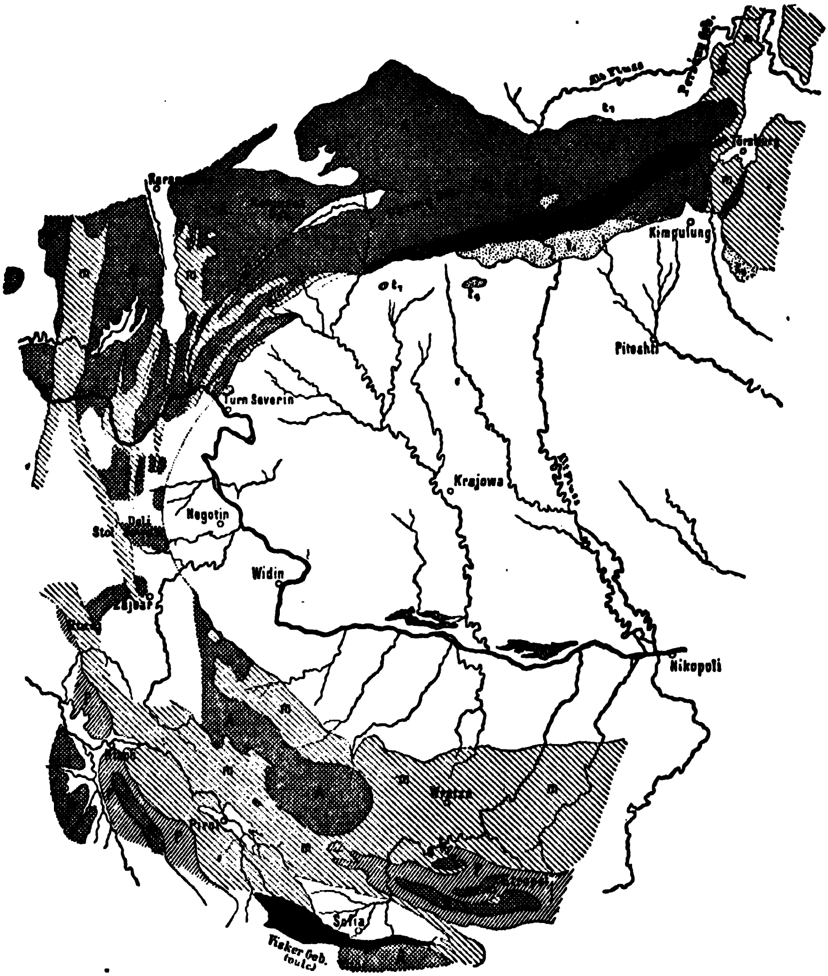



FIG. 48. *The curvature of the strike on the lower Danube.* *Gn*, The gneiss band of the frontier mountains; *A*, Archaean and granite; *p*, Palaeozoic; *m*, Mesozoic; $t_1$, Eocene.

to the east of Reshitza. To the east the chain extends as far as Gura Vau, on the Danube, above Turn-Severin; thence to the north-east it forms the border of the Roumanian plain.

An Archaean foundation is present and a long series of sedimentary, principally calcareous deposits, which range from the upper Carboniferous to the upper Cretaceous; but the series is not complete, and Trias lime-

stone, for example, has not yet been observed. The Lias contains coal. The whole Banat complex consists of a succession of alternating bands, one set exhibiting the Archaean foundation, the other wedged-in limestone cores. At the junction between them normal superposition is sometimes observed, sometimes folding or overfolding, at others fracture. The last case is probably the most frequent. Generally speaking the bands on the west are broader than those on the east. They are not parallel; those on the east run in arcs curved to the south-west, those on the west, on the other hand, are straighter and run more nearly from north to south. They thus meet and cut each other off at acute angles on the lower course of the Cerna in the neighbourhood of Mehadia.

Let us begin our description with the eastern part. The first band is only represented, according to Drâghicénu's map, by two fairly long patches of limestone, which separate the arc succeeding immediately to the west from the recent Tertiary land.

The second band is Archaean; it rises independently from the plain to the east of the upper Motru and runs south-west towards the Danube.

The third is limestone: according to the data given by Stefanescu it begins near the border of the mountains at Dobritza on the upper Suchodol, and runs after a short interruption in a curve through Baia de Arama towards Verciorova on the Danube.

The fourth band, composed of Archaean rocks, becomes narrower north of Baia de Arama, is traversed by the river Bahna, and its western edge, shortly before reaching the Danube, crosses the lower course of the Cerna above Old Orsova.

Now the cutting off begins. A great band of limestone, the fifth band, meets the seventh on the left bank of the Cerna, and so cuts off the sixth, which is none other than the great Archaean ridge, which we have followed as an anticlinal under the name of the Mundra range from the river Alt up to the summit of the Páring mountains and then on the south side of the Wallachian Schyl. The cutting off then becomes more frequent, and it is not worth while to trace the process further in detail. Then follows in the west the broad band of Archaean rocks which runs from Karansebes to the Danube; within this the subsided basin of the Almás is let down, and we may therefore call it the zone of the Almás; finally the broad limestone zone of Steyerdorf, as the last and most westerly band, concludes the series.

The Danube now cuts through this remarkable complex in the grandest erosion valley of Europe. Stormily the stream forces its way through the narrow defiles and falls foaming over the rocky barriers in its course, smooths itself out again in the broad reaches, and plunges anew over fresh reefs. Seven cataracts, corresponding to as many reefs of rock, cross the Danube; they are formed of granite or gneiss, gabbro, Lias sand-

stone, or white Jurassic limestone, according to the nature of the bands which strike across the river towards Servia.

We do not possess any connected geological survey of the adjacent part of Servia, although the fact that the ore-deposits of the Banats extend towards this country, along with the mountains themselves, has for a long time led mining experts to visit it. The most valuable information is contained in Herder's Itineraries and a new and compendious book of travels by Tietze[1]; and this, if we are content to confine ourselves to the course of the Archaean and limestone bands, is at least sufficient to guide us to some general results.

First of all it is certain that the limestone zone of Steyerdorf is continued very far within Servia; Tietze recognized it near Majdanpek and on the Stol, and both these places occur on its eastern edge; according to Andrée the western edge runs in the neighbourhood of the mining town of Kuchaina[2]. From this region it proceeds, probably split into two, and certainly very much narrowed, to the south-east over the Rtanj and then on to the Osren above Alexinatz, as Herder informs us.

The Archaean band of the Almás, the broadest of all, crosses the Danube, occupies the whole space between Milanovatz and Majdanpek, runs to the south-east to the Deli Jowan, and probably unites there with a band coming from the east; to the south we meet the same rocks in Zajcar.

In Servia the eastern arcs are as yet only incompletely known. To the west of Negotin they all appear to have vanished[3].

If we review the arrangement of the several elements of which the Banat mountains are composed and their probable continuations to the south, it is evident that the more strongly curved and narrower bands of Roumania on the east which strike to the south-west, gradually cut each other off and disappear, in part to the north, in part perhaps a little to the south of the Danube; while the broader, less arched western bands are

[1] S. A. W. Freiherr v. Herder, Bergmännische Reise in Serbien, 8vo, 1846, pp. 43 et seq.; E. Tietze, Geol. Notizen aus dem nordöstlichen Serbien, Jahrb. geol. Reichsanst., 1870, XX, p. 597.

[2] T. Andrée, Die Umgebung von Majdan-Kucaina in Serbien, Jahrb. geol. Reichsanst., 1880, XXX, p. 12, pl. i.

[3] North-west of Zajcar, near Gamsigrad, limestone again appears, but a broad mass of older rock, which Herder encountered along the little Timok, makes it probable that the limestone band is here split in two, and a fresh strip of Archaean makes its appearance. Herder and Tietze have shown that the valley of Porecka, south-east of Milanovatz, is accompanied by a band of limestone striking north and south. The high ridge of the Strbatz, east of Mosna, may be regarded as a continuation of the Roumanian arcs; it consists of mica-schist; on its crest limestone is said to occur. Even in the depression west of Brsa Palanka, Herder mentions mica-schist, but on the way from Negotin to the mountains only the horizontal shelly limestone, evidently the Sarmatian deposits.

continued a long way towards Servia, their direction passing gradually from south-south-west or south to south-south-east or south-east [1].

We have seen how the great Flysch zone of the Carpathians, then the mass of Monte Leota, and next the gneissose range of Monte Cozia, constantly directed to south-west or south-south-west, dip finally beneath the plain; how the long range of the Mundra is cut off and terminates on the lower Cerna; and now the Roumanian arcs of the Banat mountains directed to south-west, south-south-west, or south similarly disappear.

From the pass of Tömös onwards, new orographic elements constantly make their appearance on the west, to again disappear, and it is only the most westerly of the bands of the Banats which accomplish the full sweep to south-south-east or south-east. *The whole mountain system extending from the south-east of Transylvania, around the plain of the Danube, and down through the east of Servia has been subjected to a general torsion.*

The fissures arising from this torsion, especially those of the outer bands, and particularly where the Archaean meets the limestone, have been injected at various places by volcanic rocks, such as have been described as syenite, timazite, banatite, but are now more generally known as diorite.

Whatever name may be chosen—a competent authority, G. von Rath, points out a resemblance to the tonalite of Monte Adamello [2]—it remains in any case certain that these rocks have profoundly altered the Cretaceous limestone at the zone of contact and have surrounded themselves with beds of ore; they are, therefore, more recent than the Cretaceous formation, and the great distance to which they are prolonged to the south is best seen from the circumstance that the first specimens described in any detail, Breithaupt's timazite, were obtained from the neighbourhood of Zajcar in Servia. With amazement G. von Rath describes 'whole mountains of garnet,' which have been formed by contact. The most important of the volcanic lines is shown in Fig. 21, p. 162 [3], and the way in which it swerves off from the boundary of the limestone at a very acute angle as it proceeds to the north is in complete accordance with the character of a fracture produced by torsion.

Let us, however, return to the strike of the individual bands.

Hitherto we have regarded them simply as tectonic elements of the mountains, but they often possess a highly complex structure of their own. Kudernatsch has shown that the north part of the limestone zone of

[1] The fundamental features of the arc appear with fair distinctness on Toula's map, Geol. Uebersichtskarte der Balkan-Halbinsel, Petermann's geogr. Mitth., 1882, pl. xvi.

[2] G. v. Rath, Vorträge und Mittheilungen; Sitzungsber. d. Nied.-Rhein. Ges. f. Natur- u. Heilkunde zu Bonn, Sitz. v. 13. Jan. 1879, p. 39.

[3] On this little map the names of the two towns Moravicza and Dognácska have been accidentally interchanged.

Steyerdorf is traversed by two erect anticlinals striking to south-south-west, or rather by two 'distensions of the earth's crust burst open along their longitudinal axis,' and with an inverted eastern border; and in the south part Böckh has described in detail the occurrence of great longitudinal faults; the eastern boundary of the limestone itself is there formed by a dominant fault, which brings the Cretaceous into contact with the granite.

In like manner Hauer and Stache have shown that the sedimentary band of the brook Sirinnia, which lies near the eastern border of the Archaean zone of the Almás, is overthrust to the east[1]. In all these cases it is scarcely a question of simple folding, like that produced by tangential movement in the Jura, but rather of those complex phenomena of fracture, bursting, and crushing, which must necessarily result from great torsion. The repeated overthrusts to the east correspond to the direction of the torsional movement.

Let us now return to the south.

In following the band of limestone across the mountains of Rtanj and Osran, and tracing the older formations as far as Zajcar, we have reached the limits of that region, with which Toula's extensive researches in the western Balkans have made us acquainted. Through these researches the great extension of the Archaean rocks of the Balkans to the north-west, through the Balkans of Etropol and Berkovitza as far as the immediate neighbourhood of Adljé and Zajcar, first became known; they are supplemented in the west by the surveys of Zujovic, which extend to beyond Kurshumlje[2]. The result may now be read on the map. We see that the limestone zone of Steyerdorf extends in the west over the Rtanj and Osran and then, perhaps accompanied by a secondary chain in the east, into the great limestone zone of Pirot, a fact which was recognized by Boué and confirmed by Toula[3]. We see besides that the Archaean band of the Almás,

[1] J. Kudernatsch, Geologie des Banater Gebirgszuges, Sitzungsber. Akad. Wiss. Wien, 1877, XXIII, p. 40 et seq.; J. Böckh, Geol. Notizen von der Aufnahme d. J. 1881 im Comitate Krassó-Szörény, Jahresber. d. k. ung. Geol. Anstalt f. 1881, p. 8; F. v. Hauer, Kohlenvorkommnisse von Berszaszka, Verh. geol. Reichsanst., 1870, pp. 167, 168; E. Tietze, Geol. und pal. Mittheilungen aus dem S. Theile des Banater Gebirgsstockes, Jahrb. geol. Reichsanst., 1872, XX, pp. 94-99.

[2] In particular, F. Toula, Grundlinien der Geologie des westlichen Balkan, Denkschr. Akad. Wiss. Wien, 1882, XLIV, pp. 1-58, and map; Geol. Untersuchungen im westlichen Theile des Balkan, X, von Pirot nach Sofia, Sitzungsber. Akad. Wiss. Wien, 1883, LXXXVIII, pp. 1279-1348, and map, and for parts of the Balkan lying further to the east, preliminary report by the same in the Anzeig. Akad. Wiss. Wien, Oct. 23, 1884, pp. 197-202; further: J. M. Zujovic, Contributions to the Geology of the Kingdom of Servia, I (in the Servian language), 8vo, Belgrade, 1884, map.

[3] 'It is this band of Cretaceous rocks which, striking from south-east to north-west, runs from Bulgaria through the east of Servia and the country east of the lower Morava (which forms the western boundary), reaches the Danube, and there joins the eastern sedimentary band of the Banat mountains, as may be seen from the representation given by Boué on his manuscript map.'—Toula, Grundlinien, p. 40.

united with a number of ranges which join it on the east, now reaches the Archaean zone of the Balkans, so that the principal zone forms towards the south-east the Swati, Nikola, and Berkovitza Balkans, and finally accomplishes in the Etropol Balkan the full sweep from south-east to due east and west, i. e. into the normal direction of the principal chain of the Balkans. At the same time the hills of mica-schist to the west of the limestone range, in the Wershetz and Lakva mountains of Hungary, correspond in position to the mica-schist of Krushowatz, and to the ancient schist on the west of the Rtanj, near Alexinatz, which extends to Nish and the west of Pirot.

*The connexion between the Carpathians and the Balkans is effected by a general torsion in the trend of the mountains.*—

The mountain frame around the Roumanian plain strongly recalls the arc-shaped enclosure of the western Mediterranean formed by that distant branch of the Alps which runs from North Africa past the Rock of Gibraltar to the Betic Cordillera. The resemblance is the greater since there it is the straits of Gibraltar which profoundly influence the physical nature of a not insignificant part of the earth's surface, and here it is the valley of the Danube which determines the drainage of a great part of central Europe, while neither of these transverse furrows are in any way indicated in the original scheme of the mountains. The resemblance is nevertheless merely superficial. In the western Mediterranean the folding of the mountains is directed towards the exterior, the bottom of the sea itself is a sunken area like that of the northern Carpathians. In the Balkans the case is reversed. The torsion has caused the several bands of the mountains to disappear one after the other, and the Balkans are faulted down on their southern flank which looks away from the plain, while their sedimentary girdle slopes down on the north towards the plain. The western Mediterranean is bordered by the inner side of the mountains, the Roumanian plain by their outer side. As a consequence the margin of the Mediterranean is marked by recent volcanos, as at the Cabo di Gata and elsewhere—indications of local subsidence, or it may be of the region of marginal fractures; but no such crowning with eruptive centres occurs around the Roumanian plain; on the contrary, the basaltic hills which do occur are found on a transverse line, running from Sistow to the south, as has been pointed out by Toula.

The torsion explains also the structure of the Balkans. This is clearly shown by the manner in which they join with the adjacent chains on the north. In the Berkovitza Balkan spotted schists, such as we are accustomed to find in regions of volcanic contact, have been recorded, and Toula does not omit to mention the resemblance of certain eruptive rocks, such as those of the Isker, to the banatites. Towards the north a sedimentary zone rests against these most westerly masses of the Balkans. It

begins near Rabis and Belogradchik, where Permian, Trias, Tithonian, and Cretaceous beds occur within a narrow space. Further to the east the Cretaceous deposits increase rapidly in breadth and form the whole outer slope of the exterior chain and the basement of the plain, so that they already crop out on the bank of the Danube, at the confluence of the Isker. This sedimentary covering is the counterpoise to the sunken Cretaceous zone north of the Carpathians; owing to torsion it crops out gradually from the plain, from Belogradchik onwards, with a flat and as it were twisted surface. In some places it lies in longitudinal folds, but is nowhere inverted. To the south it is succeeded by a poorly developed zone of older Mesozoic sediments, chiefly Jurassic; then comes a band of Palaeozoic deposits still more feebly represented, and finally the crystalline zone of the Balkan.

With these rocks we reach that remarkable zone of fractures which, according to Hochstetter, follows the whole southern border of the Balkans, from Pirot to cape Emineh on the Black sea. It is 450 kilometers long, traverses rocks of the most varied description, and is accompanied by numerous hot springs and long bands of eruptive rocks[1]. Fritsch has urged, not wholly without reason, that the relative heights of the sedimentary rocks are not consistent with the existence of so great a 'fault,' and I also think that this designation is hardly suitable to the dislocation[2]. But the fractured zone, bent at its western extremity towards Pirot, exactly fits into the group of great torsional lines, and it is impossible to say to what dimensions disturbances might not attain as a consequence of this great deflexion in the course of the mountains.—

Hitherto we have only spoken of the principal chain of the Balkans. To the west of Sofia, however, on the north side of the Vitosa, there rises the andesite mass of the Lünlün and Visker mountains, and hereabouts the great limestone band of Pirot bifurcates. According to the precise data furnished by Hochstetter, one branch proceeds west of the Vitosa down towards Kustendil and Dubnitza to the Karasu, but of its further course nothing is known. On the Vitosa itself, however, a long train of syenitic masses begins, which at first runs parallel to the south border of the chief chain of the Balkans, and then bends more to the south-east. Hochstetter regards these masses as 'decidedly eruptive,' and includes among them the masses of Samakovo in the Istrandsha mountains, that of Bujuk Darbend on the left bank of the Tundsha, and of Vakovo on its right bank, of Trnovo on the Maritza, of Philippopolis, the magnetite rich syenitic mass of the Slakutsha mountains on the Isker, and finally the

[1] Hochstetter mentions the places—Misiwri, Aidos, Karnabat, Sliwno, Kisanlik, Kalofer, Karlowa, Slatica, Pirot: F. v. Hochstetter, Die geolog. Verhältnisse des Ö. Theiles der europäischen Türkei, Jahrb. geol. Reichsanst., 1870, XX, p. 399.

[2] C. v. Fritsch, Beitrag zur Geognosie des Balkan; Vortrag gehalten in der Naturf. Gesellschaft zu Halle, 15. Nov. 1879, pp. 9, 10.

mighty syenite mass of the Vitos. The manner in which this remarkable line of syenitic intrusions (also about 450 kilometers long) is connected with the great torsion cannot be determined in the present state of our knowledge; the Vitosa at its western extremity is driven forwards towards the north-west in the direction of the great torsion.—

Let us now glance at the more recent formations. The Eocene appears to have rested in transgression on the frontier chain of Transylvania, but on the Lotru it is nevertheless crushed in consequence of later mountain movement. The next deposit definitely recognized within the region of torsion is the second Mediterranean stage; it is only to be seen near Plevna, where, according to C. von Fritsch, it rests directly upon the Cretaceous. Then follows the Sarmatian stage, which lies horizontally against the inner arcs, and then the series of more recent, not marine deposits, which are found chiefly in the northern part of Roumania.—

The Balkans present, as we have seen, a broad border of sedimentary deposits, chiefly of Cretaceous age, which slope gradually down towards the north. All the inner zones disappear to the east beneath the eruptive mass of Burgas; cape Eminch consists of Cretaceous limestone. The lower Cretaceous presents a Carpathian, i.e. a south European facies, as in the Crimea; the upper Cretaceous, on the other hand, resembles that of north Europe, again as in the Crimea. It is succeeded near Varna by the Nummulitic limestone, already lying horizontal, once more as in the Crimea, while sporadic exposures of the second Mediterranean stage and the wide extension of the Sarmatian deposits equally recall the Crimea. This part of the stratified sequence is thus in close accordance in both regions, and so far as this sequence can be taken as a sign of tectonic connexion at all, it certainly leads us from the Balkans to the Crimea.

The upper Jurassic, which lies beneath the Neocomian, also appears to be closely related to that of the Crimea. But the unconformity below the Neocomian and the great development of the Lias shales are so far not known in the Balkans. On the other hand, still lower and clearly characterized members of the sedimentary series appear in the Balkans, which are not known either in the Crimea—where the beds below the Lias are not visible—nor in the Caucasus. To the north of the hypothetical line of connexion the mountains of Matchin present themselves with a completely divergent trend, and with a different stratified sequence, distinguished by the marked development of the marine Trias.

Nevertheless the correspondence in the disposition of the beds, in the strike, and in the stratified sequence above the Jurassic is so great that I do not hesitate, while awaiting further information, to adopt the hypothesis, supported by Spratt, E. Favre, and Lagorio, of the original continuity of the Balkans and the Crimea.

We must not, however, overlook the fact that the Balkans still show

in the folds of the northern zone, unimportant as these may be, some traces of the general European movement towards the north; the northerly dip of the folds in the Sarmatian on Kertch and Taman outside the great mountain ranges also indicates a certain movement to the north, as likewise does the folding of the northern zone of the Caucasus, especially in Daghestan, and as well the outer Sarmatian folds to the north of Vladikavkas.

Beneath this sedimentary zone, inclined to the north, and in places also folded in the same direction, the Caucasus reveals, however, that mighty inversion to the south which is the distinctive character of its great southern slope. It forms, as Abich says, a great monoclinal fold, and the dip of the Lias shows that the inversion to the south cannot have occurred before the Mesozoic period. But the exterior surface of this fold, turned towards the north—originally, no doubt, a level plain of deposition—nevertheless bears a series of sediments, which have been pushed to the north. In no other mountain chain is such a peculiar twofold expression of the tangential movement known; and here we are precisely in that region in which the limit between the Asiatic movement to the south and the European movement in the opposite direction must be sought.

*The syntaxis of the Iranian-Tauric chains.* The outer Iranian chains afford indications of a subordinate syntaxis only at one point, on the straits of Ormuz. With the inner chains the case is different. The Paropamisus with its convexity turned to the south forms in north Afghanistan the inner arc corresponding to the eastern part of the outer Iranian arcs, but as it proceeds with an undeviating north-westerly direction through the Kurendagh to the Caucasus, it completely leaves the region of the Iranian folds. In its place a second arc appears, which corresponds to the western part of the outer Iranian chains; the northern border of this at the same time bounds the Caspian sea, but, as we shall see directly, also shows a tendency to prolong the branch, which runs to the north-west. This second arc is the range of the *Albourz.*

As to the manner in which the Paropamisus and Albourz meet we possess some noteworthy data. First of all the north-western prolongation of the former is followed by those very regular parallel chains of eastern Khorassan, which have been recently explored by Lessar; as the offshoots of these we must regard the chains of slight elevation encountered by Sievers on the Atrek. The corresponding part of the Caspian coast appears to be occupied by the petroleum-bearing Tertiary beds, which we have already met with on the declivities of the Balkash. Ach-Tepe, north of Tchikishliar on the lower Atrek, is a mud volcano[1].

[1] P. M. Lessar, Bemerkungen über Transkaspien und die benachbarten Landstriche; Petermann's geogr. Mitth., 1884, XXX, pp. 281–296, pl. xi. The northern of these chains have furnished the lower Cretaceous Ammonites mentioned by Neumayr, Verh.

The parallel ranges of the eastern Khorassan are thus completely flattened out towards the Caspian sea, but towards the south another parallel segment appears, which, although orographically united with the Albourz, must be distinguished from it in structure.

From Tietze's study of the structure of northern Persia, which, with Grewingk's earlier description, is the chief source of our knowledge of this region, it appears with the greatest clearness that between Ashref and Asterabad a range directed to the north-west reaches the shores of the Caspian sea and abruptly ends there. It includes the heights on the south border as far as Shahrud and Deh i Mullah and is, at least in part, overturned to the south-west, so that on the south border of the mountains and near Tash the coal-bearing beds of the Lias plunge to the north-east beneath a Palaeozoic zone, which proceeds towards Asterabad, where it stands vertically. The oldest rocks of this mountain segment are found in the north-east near Asterabad; the most recent are probably represented by a Cretaceous zone, which strikes from the Caspian near Ashref into the mountains[1].

Tietze is entirely right in regarding the Albourz as 'a repetition on a small scale of the features which determine the configuration of the continent of Central Asia.' We here see an arc moved to the south like so many others already mentioned, and all the results obtained by Muschketoff for the chains in the interior of Asia are applicable to the Albourz. The front of the arc lies west of Firuskuh, and in this region ranges also appear running from east to west. That part of the arc which trends to the north-east terminates near the Cretaceous band of Ashref, in a manner not yet precisely known to us in detail. As in the case of so many chains of the interior of Asia, the branch which runs to the north-west is much longer than the other. The Archaean foundation is only visible on the north side and only on the longer north-western branch, for an isolated and locally limited exposure of syenite on the south slope in the Keretch valley west of Teheran can hardly be regarded as representing this foundation. Notwithstanding the occurrence of Archaean rocks on the north side of the arc, the stratified sediments present as a rule a contrary dip to the north, and this although the beds are not inverted but in normal succession. This points to the presence of imbricated structure in certain parts of the Albourz. In this way too the form of the outer border finds an explanation. Tietze

geol. Reichsanst., 1881, p. 325. G. Sievers, Die russische militärische Expedition nach dem alten Oxus-Bette, &c., Petermann's geogr. Mitth., 1871, pp. 287–292.

[1] E. Tietze, Bemerkungen über die Tektonik des Albursgebirges in Persien, Jahrb. geol. Reichsanst., 1877, XXVII, pp. 375–430; a few data as to this phenomenon even so long ago as 1853 in C. Grewingk, Die geognost. und orogr. Verhältnisse des nördlichen Persiens, 8vo, Petersburg, 1853, 148 pp. and map (from the Verh. Min. Ges. Petersb., 1852, 1853).

describes it as a broken arch with the beds dipping to the north. The foot-hills of Shah-Abdalusim to the south also present a steep slope to the south and the beds are inclined to the north; this is also the case in the Siakuh. In considering these monoclinal foot-hills, we must, however, not overlook the fundamental difference which exists between the outer border of the Albourz and that of the Himálaya or the Carpathians. To the south of the Albourz we stand, not on a tabular and alien foreland, but in the midst of the Iranian folds, of which the Albourz itself forms part, and further to the west this unity of the Iranian folds becomes still more unmistakable, owing to the intercalation of several parallel ranges, which extend as far as the chains of the Zágros.

This conception of the Albourz as an arc moved to the south reproducing the central Asiatic type is not affected even by the position of the colossal *Demavend*, the volcanic cone of which, superposed over the middle of the arc, rises about 20,000 feet above the sea. Tietze has clearly shown that this stupendous accumulation is of a later formation than the orographic arc on which it stands, and that the general plan of the existing valleys was already determined before Mount Demavend was built up [1]. Here we may apply all that has been said on an earlier page with regard to the great volcanos of Sumatra and the Caucasus, and especially as to the relations which exist between them and the foundations on which they rest.—

The first great parallel range which accompanies the north-west branch of the Albourz is the *Karaghan Dagh*, from 8,000 to 9,000 feet in height. It has been crossed by Wähner and found to consist of syenite, porphyry, and other eruptive rocks associated with deposits, which, so far as is known, are not older than the Eocene; the petrographical composition is thus such as we have so often met with before in other mountain chains. On both sides of the range the first Mediterranean stage and the salt-bearing series are present; they have also been involved in the Iranian folding [2].

The ranges between the Albourz and the chains of Zágros now increase in number; they run through Aberbijan, and great volcanic mountains, such as Sawalan and Sahend, rise between them; they reach the Araxes, and here new folded ranges appear even to the north of the line of the Albourz, as though the ranges which have sunk between Ashref and Asterabad into the Caspian sea, and those which have disappeared on the Atrek beneath the steppe, were again coming into view [3].

[1] E. Tietze, Der Vulkan Demavend in Persien; Jahrb. geol. Reichsanst., 1878, XXVIII, pp. 169–206, map. Stebnitzky, in opposition to other observers, does not admit a greater height than 18,600 feet (according to trigonometrical measurements from the Caspian sea).

[2] F. Wähner, Letter in the Anzeig. Akad. Wiss. Wien, 22 June, 1882, pp. 143–145.

[3] Khanykof in Abich, Bull. Acad. Pétersb., 1858, XVI, pp. 340–352. In determining

In Armenia, however, the volcanic ejectamenta and lava flows attain such dimensions that they determine the form of a great part of the surface. The folded chains are faulted down and covered up, so that the fundamental features of the structure are completely masked. For deeper insight many years of devoted labour were required, a great problem was propounded; it found the master who was to solve it in Hermann Abich [1].

In the following paragraphs I hope to give with sufficient exactitude the chief results of Abich's numerous treatises on this region.

The west Iranian chains (Zágros and Albourz) proceed from the south-east towards Armenia; another series, equally important, advances from the south-west. These are the Tauric chains. They occupy the whole region comprised between the southern border of the Taurus and the shores of the Black sea, near Trebizond; the two longitudinal valleys of the Djoroh which unite near Beiburt, mark the general direction of the trend from east-north-east to north-east. The two chains, the west Iranian and the Tauric, tend to unite, but here the result is not, as on the Jehlam, syntaxis, either in an arc or at an acute angle; the region of syntaxis has collapsed, and it is here precisely that the mightiest volcanic regions are found, as, for instance, the volcanic table-land from Ardahan to lake Tchildir, the plateau of Kars, that of the Alagéz, the broad base of Ararat, of Tandurek, and others. The Meskian mountains, however, composed of Archaean rocks, which east of Kutaïs extend with a north-east trend to the foot of the Caucasus and form the watershed between Rion and Kur, are a part of the Tauric chains.—

I cannot here enter into detail as to the manner in which the subsidence of the syntactic chains has taken place, but I will by way of example at least attempt to describe the chief features of the country between Ararat and lake Goktchai, as they appear from Abich's descriptions [2].

The cone of *Ararat* rises 16,926 feet above the sea and descends on the north and north-east to the valley of the Araxes, which in this part of its course has an altitude of 2,500–2,600 feet: the height of the cone itself therefore exceeds 14,000 feet. It rests on a basis of in-sunken Devonian and Carboniferous formations, which crop out at the bottom of

the directions of the mountains it is necessary, in order to find the true strike of the folds, to exclude the volcanic regions from consideration.

[1] H. Abich, Das Meschische oder Karthli-Imeretinische Gränzgebirge in geol. und climat. Beziehung, Bull. Acad. Pétersb., 1851, IX, pp. 29–45; Geol. Beobachtungen auf climat. Reisen in den Gebirgsländern zwischen Kur und Araxes, 4to, Tiflis, 1867; also, Geol. Forschungen in den kaukasischen Ländern, II, Geol. des armen. Hochlandes, Westhälfte, 4to, Wien, 1882, particularly pp. 5–11, and in many other places.

[2] H. Abich, Der Ararat, in genetischer Beziehung betrachtet, Zeitschr. Deutsch. geol. Ges., 1870, XXII, pp. 69–91, pl., and in particular Geol. Forschungen in den kaukasischen Ländern, II, Atlas, map ii.

the valley and also on the south-east side, where they form the shoulder of the Maku mountains.

On the other side of the Araxes, the same Palaeozoic formations appear; their beds dip to the north and form a steep scarp on the Dsynserly-dagh, and then serve as the basement of the next chain of folded sediments. Dsynserly-dagh, however, is itself a part of the south Karabagh, one of the west Iranian parallel chains which run down from the south-east.

The south Karabagh sinks, before reaching the Goktchai, beneath the broad volcanic plateau of the Agmangan; this rises in the Aghdagh to 11,711 feet, and its east side forms the south-west margin of the lake, while the west side slopes down to the Araxes.—The second parallel chain is completely buried under the volcanic plateau of the central Karabagh.—The third parallel chain, the northern Karabagh, terminates at the south-east corner of the lake.—The next chain, the Ganja and Goktchai mountains, also closely packed against the preceding ranges, forms the north-east shore of the lake, and shows a tendency to leave the north-westerly direction of the preceding chains and to pass through an arc into a westerly direction. Indeed the western prolongation of the Pambak mountains does attain an almost due east to west strike; this chain is suddenly broken off, to the west of the north end of the lake, opposite the ash cone of the Alagaz, 13,436 feet in height. To the north the mountains of Besorbdal running due east and west meet the offshoots of the Pambak, which are directed to the west; near Alexandrapol the crescentic parallel chains sink beneath the widely-extended volcanic accumulations in which the upper Arpatchai has excavated its bed.

Thus the Iranian arcs seek, as it were, to unite with the Tauric arcs, and if we look at Abich's beautiful map of Russian Armenia we shall be tempted to make a comparison with the 'Lägern,' the eastern spurs of the Jura, although the Lägern are only ramifications and not syntactic arcs.

This is even more applicable to the spur which further south runs across from the Tauric chains as the Tchatin-dagh. In order to properly define its position, we must return to Ararat.

The volcanic ridge of Ararat lies directly south of the curve connecting the chains running to the north-west with the spurs directed to the west. A similar curve is indicated in the alignment of the volcanos. Abich emphasizes the fact that the line in question runs to the north-north-west from the Little to the Great Ararat and to the Kipgoell, while from the Kipgoell the mighty chain of volcanos turns due west to lake Baluchgoell, as though these volcanos stood on a cleft in the strike of the syntactic chains. Towards the south they descend to the plateau of Bajuzid, and this is followed on the south by the volcanic series of the Tandurek, which also runs to the west.

To the north of Baluchgoell, however, i.e. north of the western end of the Ararat series, there rises out from beneath the volcanic accumulations the extremity of that great spur, the Tchatin-dagh. It is the most characteristic of the syntactic arcs. It encloses the region of the sources of the Murad, separates it from the Araxes, and proceeds far to the west-south-west.—

The Caucasus, with unaltered course, runs obliquely past the region of syntaxis, just as the Thian-shan passes the syntaxis lying in front of it on the south; and now we are able to recognize on the map those places where the contour of the inland seas is determined by the structure of the land. The southern shore of the Caspian corresponds with the arcs of west Iran; that of the Pontus, in the bay of Trebizond, with the Tauric arcs, and the promontories of Apsheran and Taman coincide with the trend of the Caucasus.

Striking as the contrast between the direction of the mountains of Kashgar and that of the Thian-shan may be, yet I know of few examples on the whole surface of the earth of a contact between two different orographic directions, so intimate as that on the upper Rion between the north-easterly trending Meskian mountains and the south foot of the Caucasus. On the outer border of the Carpathians we have seen the folds of a great mountain range approach towards and even advance over another range—the Sudetes, in which the succession and character of the sediments are essentially different. In the Caucasus we now witness the encounter of two folded ranges having a different trend as well as a fairly different development of the strata. It is particularly the subdivisions of the Cretaceous system rich in Actaeonella and Hippurites (recalling the valley of Gosau), and the richly fossiliferous older Tertiary beds, which appear in the Meskian mountains and further to the south, with characters such as distinguish our Alps but are alien to the great zone of the Caucasus.

The Tauric chains are not strictly parallel. The most northerly ranges, of which the shores of the Black sea near Trebizond form part, are deflected, in their course from Batum through Lasistan, from south-south-west to south-west and west-south-west. The more southerly ranges preserve the gentler curve with which we became acquainted in the Tchatin-dagh, and which recalls in so many respects the Tertiary arcs on the Jehlam (Pl. IV); their prevailing direction is west-south-west [1]. Unfortunately neither the excellent works of Russegger and Tschihatscheff, nor Kotschy's travels, afford us more than an incomplete knowledge of the structure of the Anti-Taurus and the Bulgardagh. We know, however,

[1] The direction of these chains is most clearly seen from the little map of Tschihatscheff in the Bull. Soc. géol., 1851, 2e sér., VIII, pl. vi.

that the chain continues in a west-south-west and south-west direction to Tarsus on the coast, and that parallel ranges of forelying hills terminate on the lower Orontes.

Černik gives a general survey of the southern region of syntaxis; from which we learn that in the valley of the Euphrates, the clays containing asphalt extend far beyond Deir, and that in Syria gypsiferous Tertiary strata occur between Homs and Palmyra, probably identical with the 'gypsiferous series' of Loftus already met with on the border of the Zágros and evidently widely distributed in Mesopotamia. Somewhere in the locality where the outer borders of the Iranian and Tauric chains should meet lies the broad basalt mass of the Karadja-dagh, and on a north-eastern spur there rises the sombre town of Djarbekr, partly constructed of basalt. A curious question is suggested, however, by the observations of Russegger and Černik. A range of considerable importance, the Jebel Senayeh, runs down from the east side of the Anti-Libanon in a north-east direction, and passes beyond Palmyra. At the same time the Libanon and Anti-Libanon diverge perceptibly from the meridional line of the Jordan valley, and run to the north-north-east, as though they were about to enter into relation with the Taurus, of a nature which must for the présent remain indeterminate [1].

In a corresponding manner the structure, the nature of the rocks, and the position of Cyprus show that in this island we have before us the continuation of the Taurus. Cyprus consists of two arc-shaped mountain masses, separated by the plain of Nicosia. The northern ridge, which forms the whole north coast as far as cape Andreas, consists, as we know from Gaudry and Unger, of Cretaceous limestone and Flysch, with intrusions of gabbro, greenstones, and serpentine. The great southern chain, the Troodos, consists exclusively of the latter rocks, exactly like the mountains of Antioch. Recent Tertiary deposits lie in the basin of Nicosia [2].

[1] J. Černik's Techn. Studien-Expedition durch die Gebiete des Euphrat und Tigris, edited by A. Freihr v. Schweiger-Lerchenfeld; Petermann's geogr. Mitth., 1875, 1876, Ergänz.-Hefte 44 and 45, maps, in particular I, p. 10; also the little map in Puchstein, Sitzungsber. Akad. Berlin, 1883, I, p. 29. The serpentine in the valley of the Tigris has been described by W. Smyth, Geological Features of the Country round the Mines of the Taurus in the Pashalic of Diarbekr, Quart. Journ. Geol. Soc., 1845, I, pp. 330–340.

[2] A. Gaudry, Géologie de l'Île de Chypre, Mém. Soc. géol. de Fr., 1859, 2e sér., VII, pp. 149-314, map; F. Unger and T. Kotschy, Die Insel Cypern, 8vo, Wien, 1865. Cyprus appears indeed to be simply the continuation of the two bands of serpentine, Euphotid and Cretaceous limestone, which under the names of Mussa-dagh (Amasus) and Jebel Okrah (Cassius) reach the Mediterranean on both sides of the Orontes; this supposition is only opposed by the fact that the north part of the Jebel Okrah presents, according to Russegger, a strike in the opposite direction (Reisen, I, pt. 1, p. 450). The relations of Libanon to the Taurus are an open question and fresh investigations are much to be desired. The Tertiary beds of gypsum appear to run from Schugr on the upper Orontes and to reach the sea; according to Pruckner they occur on the summit of the Jebel Okrah. Antioch stands, according to Ainsworth and Russegger, on serpentine.

The *Dinaric range*. Our previous descriptions of the Alps have shown that the relations of the Dinaric range are peculiar and even abnormal. We have been unable to include it in the diagrammatic representation which we have given of the trend-lines (pp. 232 and 480). The peri-Adriatic faults and flexures of the southern Alps, which are overthrust from the north-west, north, and north-east, meet the Dinaric flexures and faults, which are overthrust from the north-east. The latter determine the course of the Dalmatian coast; they run towards the south-east or south-south-east. In the same direction strikes that series of long folds which begins already in the neighbourhood of Laibach, includes the Karst, and in Bosnia, Herzegovina, and Montenegro exposes Palaeozoic rocks in broad anticlinals.

To the north-east of these Palaeozoic rocks, there lies a zone of Flysch and serpentine which makes its first appearance in the south of Croatia. This, as Mojsisovics has shown, is held fast, as it were, against the Save by isolated granite bosses which protrude along its outer border; it then proceeds to the south-east and east-south-east. To the south-west of the Palaeozoic formations, a zone of Cretaceous limestone and Flysch extends along the margin of the Adriatic sea, traversed by faults and flexures which take the same course: it is this zone to which we have already called attention as occurring in fragments on the Italian coast.

Tietze's latest treatises on Montenegro, and the older works of Boué and Viquesnel, show that the Dinaric chain is continued with the same trend still further to the south-east. From the investigations of Neumayr, Bittner, Teller, and L. Burgerstein in the north of Greece, as well as those of Boblaye in Morea, we learn besides that this same direction is maintained with only very trifling deviations through the Acroceraunian mountains and Acarnania, then parallel to these, through the Pindus, the Gabrovo mountains and the Aetolian Alps, as well as through the whole of the Morea as far as capes Matapan and Malia.

More recent investigations in the north of Greece, and especially the synthesis of the tectonic features by Neumayr, teach us, however, still more [1].

The whole country is thrown into folds. But while on the west Pindus and the Aetolian Alps continue the Dinaric direction to the south-east and south-south-east, on the east of these mountains all the folds exhibit a tendency to bend in an arc to the south-east and east, and finally even to the east-north-east and north-east. As arcs of this kind we may mention Othrys and its prolongation as far as the gulf of Volo, where it is completely bent round to the north-east; then Oeta and Saromata,

[1] The works in question are contained in Denkschr. Akad. Wiss. Wien, 1880, XL; M. Neumayr, Tektonischer Theil, Überblick über die geologischen Verhältnisse eines Theiles der ägäischen Küstenländer, II, pp. 383-395.

Parnassus, Helicon, and the transverse chains of Euboea; further, Cithaeron, Parnes, and again the transverse chains of Euboea. To these must be added the fragmentary arc of Gerania near Megara, the island of Salamis, Aegaleos, the hills of Athens and Pentelicus. Parallel to the arch of the Pentelicus runs the arch of Hymettus. Thus the direction in the west of northern Greece is towards the south-south-east, but in the east towards the east-north-east and north-east.

The folds bend away in an arc; but the faults repeat those of the Dalmatian coast, preserving the Dinaric direction across the successive arcs. This at least is the case with several of the longer faults. The result is that the arcs are cut up. An example of this is furnished by the fault-line which runs along the eastern border of the coast range of Thessaly and the islands of Euboea, of Andros, Tinos, Mykonos, Amurgos, and Astropalia. By these and similar faults the islands and peninsulas are bounded round about. Thus then arises that remarkable contrast between the structure of the mountains and their external contour, which finds its strongest expression according to Teller in Euboea and the bordering mountains of Thessaly.—

All these Greek mountains consist of Cretaceous limestone and Flysch, as well as diorite, gabbro, and serpentine; in Attica crystalline schists are intercalated like contemporaneous formations between the Cretaceous beds; older crystalline rocks appear only at a few points. As Spratt and Raulin have shown, precisely the same rocks form the island of *Crete*[1], where they strike almost due east and west. It would seem that on this island as on Cyprus the fragments of two parallel chains are present, and if so one would extend from the eastern end of the island to the bay of Messara, the other from the western end to the bay of Mirabella. The three promontories in the north-west of the island, Grabusa, Spadha, and Melekha, perhaps belong to a third range.

Notwithstanding the correspondence of the rocks, I should hesitate, in face of the complete difference in strike, to regard Crete as a continuation of the folds of Greece, were it not for the sharp bending round of the eastern folds, with which we have just become acquainted. This renders it extremely probable that a similar deflexion affects the chains of the west of Greece, and with this the position and structure of Crete would certainly correspond. I believe therefore that the principal Dinaric range in the west is bent in the same direction as the inner chains, and that Crete lies in the continuation of some of its folds. The Dinaric branch would thus be continued in a similiar manner through Crete, as the Taurus through Cyprus, and we should have before us the remnants of a great arc, represented in the west by the Dinaric chain with Crete, and in the east by the

[1] V. Raulin, Description physique de l'Île de Crète, 8vo, Paris, 1869, 2 vols., map.

Taurus with Cyprus, the intervening portion having disappeared by subsidence. This we will call the Dinaro-Tauric arc. It is constructed on the same type as the Iranian arc.

In this way a new region becomes marked out, which includes the west and south of the Balkan peninsula and the whole of Asia Minor; at the same time the strange insertion of the Dinaric branch in the Alps finds its explanation.

Thus the Asiatic arcs are joined by a fresh arc, and a type of structure is repeated such as we have so often met with before. Hochstetter had suspected this as early as 1876. After discussing Iran and Armenia he says: 'And for the third time the branches separate, forming on the one hand the chains of the Taurus, on the other the bordering mountains of Anatolia, to embrace once more on the peninsula of Asia Minor a plateau of steppes on a still smaller scale—the Salt steppe of Anatolia. Thus we see the fundamental plan of central Asia twice repeated in miniature in the regions of nearer Asia [1].'

The subsequent discovery of the very recent origin of the Aegean sea enables us to unite the mountains of Greece with those of Anatolia, and Neumayr, after describing the deflexion of the folds of eastern Greece, writes in 1879: 'With this [deflexion] we must in all probability bring the numerous chains into connexion which appear in western Asia Minor with an east to west trend; it is indeed not impossible that we are dealing with the extreme ramifications of the Taurus of Asia Minor [2].'

*Explanation of the spiral arrangement of the Alps.* The peculiar arrangement of the several branches of the Alps determines the outline of the western Mediterranean and the configuration of the whole of southern Europe. The uniform direction of the tangential movement finds expression in the Jura, in the main stem of the Alps together with the Carpathians, in the Mittelgebirge of Hungary, on the south-east border of the Transylvanian Erzgebirge, and in the Apennines. We have, however, already observed (p. 233) that the Pyrenees have been moved in an opposite direction to that of the spiral system; the Dinaric branch being an alien range may be disregarded.

In central and western Asia two groups of mountain ranges may be distinguished with comparative clearness, namely, those which are convex towards the south and form the syntactic arcs and those to the north of these, which are curved in the same direction but are much less convex and run out in long straight branches. Sometimes the two groups are united by intermediate folds, as to the east of Lob Nor; sometimes the contrast between them is sharp and striking, as between the Kashgar

[1] F. v. Hochstetter, Asien, seine Zukunftsbahnen und seine Kohlenschätze, 8vo, Wien, 1876, p. 24.

[2] Neumayr, loc. cit., p. 391.

mountains and Thian-shan, or between the Meskian mountains and the Caucasus.

If the Dinaric range really corresponds to a part of one of these syntactic arcs, then we might regard the main stem of the Alps as the continuation of the northern chains, that is, of the western ramifications of the Thian-shan.

We do in fact see two branches of the Thian-shan extending towards Europe.

The first is indicated by the line Alai, Nura-tau, Sheich Djeli, Mangishlak, and perhaps by the coal-field of the Donetz and by disturbances lying still further to the north-west.

The second runs from the Paropamisus through Kuren-dagh and Kopet-dagh to the Great Balkan and the mountains of Krasnovodsk, then transversely across the Caspian sea to the Caucasus. The Sarmatian anticlinals form the connexion between the Caucasus and the mountain fragment of the Crimea; this is most probably continued into the Balkans, and here we now reach that extremely violent twisting of the trend which leads us from the Etropol Balkan and the Berkovitza Balkan, through the Banat mountains and the frontier chain of Transylvania-Roumania to the Carpathians, and finally to the main stem of the Alps. At the same time we observe as a remarkable phenomenon that from the Caucasus onwards the tangential movement is not, as in the Asiatic chains, directed to the south but to the north, that the convexity of the Alpine arcs is also directed to the north, and that on the northern border of the Carpathians all the indications appear of an extensive overthrusting on to two forelands of completely different structure, the Russian Platform and the Sudetes.

In India we have seen the Salt range, the outer border of the chains of the Hindu Kush, squeezed in and twice sharply bent in S-like form across its strike. Similar phenomena, but on a far larger scale, are presented by the line which runs from the Balkans to the Alps. It would seem as if in Asia tangential movement or lateral compression had occurred almost exclusively in the direction of the meridians of longitude, but that here it had taken place also in the direction of the parallels of latitude, and it is precisely in this region that the Carpathians are driven out towards the north in so striking a fashion.

Thus the spiral arrangement of the Alps appears to be resolved. But it is scarcely possible at present to extend these comparisons further. The Pyrenees might certainly be regarded as a further continuation of the main stem of the Alps sharply bent once more across the strike, and the direction and behaviour of the strike does indeed to some extent recall the Caucasus; but at present we can offer no sort of proof in favour of such a connexion. The Apennines, together with the chains of North Africa and the Betic

Cordillera, present a remote resemblance to the great Asiatic arcs, but the course of these mountains is evidently influenced by the Spanish Meseta.

*Ural, Pae-khoi, and their foot-hills.* Far in the east, on the other side of lake Balkash, Tarbag-atai is continued in the low chains of the Tchinghtau, and Muschketoff, as I learn from communications he has had the kindness to make me, considers it probable that south of Karakalinsk a further fold exists analogous to that of the Tarbag-atai, of inconsiderable height, and more than 200 geographical miles in length; its flat ridge forms the watershed between the sea of Aral and the Irtish. Neither a direct syntaxis nor a gradual conjunction with the Ural has, however, so far as I know, yet been directly observed, and thus the Ural for the present stands opposed to the chains which come from the Thian-shan as a completely foreign element.

Its structure is nevertheless completely similar to that of those great chains. It also presents two long and almost straight branches which unite at a swelling of the mountains in a uniform and slightly curved arc; here also the structure is throughout unilateral; the tangential movement too is everywhere directed from the interior of the arc towards its outer side, and its inner border is also accompanied by ancient eruptive rocks.

The length of the whole chain of the Urals amounts to not less than 21½ degrees of latitude; the rising ground which coincides with the point of bending lies near the mountain Pareko between about lat. 64° 30′ and 65° N.; not far from this locality most of the lofty peaks occur, in particular Toell-poss, 5,540 feet high, situated in lat. 63° 54′. The two branches of the arc are of unequal length. The northern branch trends first north-north-east, then north-east, extends through only 3½ degrees of latitude, decreases rapidly in height, and terminates in lat. 68° 29′ in the Konstantinov-Kamen. The southern branch runs for a long distance in the direction of the meridian, then splits into three branches which show a tendency to diverge to the south-south-west, and finds its further continuation in the meridional double range of the *Mugodjars*, which consist of older crystalline rocks, augite porphyry, and other eruptive rocks.

Green Cenomanian sandstone lies horizontally and unconformably on certain parts of the Mugodjars, a proof of their great antiquity. A ridge of this flat-lying green sandstone, situated near the head waters of the Tchassan, represents, as Ssewerzow and Borszczow have shown, an orographic, though not tectonic, link of connexion between these low ancient chains and the horizontally stratified table-land of the Ust-Urt; and along this line of union lies the watershed between the sea of Aral and the Caspian [1].

[1] N. Ssewerzow and J. Borszczow, Geol. Beobachtungen angestellt in d. w. Theile der kirgis. Steppe, Bull. Acad. Pétersb., 1860, II, p. 202; Ssewerzow, Ist der Ust-Urt eine Fortsetzung des Ural-Gebirges? op. cit., 1862, IV, pp. 483-487. A section of the more

The southern branch of the Ural in its entire length up to the Ust-Urt extends over 18 degrees of latitude.

After what has already been said as to the unilateral structure of the Ural, it will be readily understood that all the mineral treasures, which have made this region so famous, belong to its eastern side. The west is formed by long folded ranges composed of Palaeozoic rocks. In these the tangential movement has produced such marked effects that Karpinsky's sections, from the 51st and 52nd degree of latitude, show considerable overfolding, inverted bedding, and a contrary easterly dip in the folds situated to the east; normal folds do not appear till we proceed further to the west. Thus inverted flakes appear to occur, especially between the rivers Ika and Ulak. This inversion is continued through the central Ural, where its extent long ago attracted the attention of Murchison [1].

Further to the north, between 56° and 58°, Karpinsky found coal-measures lying in long meridional folds, and extending as far as the east side of the mountains; these are transformed for considerable distances into graphite. The associated plant remains remove all doubt that might be felt as to this transformation. It is the same phenomenon observed by Toula in the eastern Alps, and must be regarded as the result of extreme pressure [2].

Those parts of the Ural, however, which afford important material for comparison, lie much further to the north in a region which has been described in a masterly manner by E. Hofmann [3], whose account, though somewhat antiquated, I now follow.

Hofmann includes in his investigations the northern part of the meridionally directed Ural, the region of deflexion, the northern branch as far as the Konstantinov-Kamen, and next on the north the chain of Pae-khoi down to the sea. On the Tchoval, in lat. 60° 50′, the whole stratified series which lies next the crystalline schists dips to the east in a reversed direction beneath the schists, and these themselves also dip to the east. This is the same inversion as that which we have already mentioned as occurring far in the south; it appears again on the Kolva in lat. 61° 20′, on the Unja, where the Carboniferous beds lie beneath the Silurian, and

northerly part of the Mugodjars is given by Jakowlew, in Helmersen, op. cit., 1883, XXVIII, p. 364 et seq.

[1] A. Karpinsky, Geological observations in the Government of Orenburg, Verh. russ. Min. Gesellsch., 1874, 2. Ser., IX, pp. 212–310, map and plate (in Russian); Murchison, Verneuil, and Keyserling, The Geology of Russia in Europe and the Ural Mountains, 4to, London, 1845, p. 463.

[2] Karpinsky, Geological studies and search for coal on the east side of the Ural; Gornoi Journ., 1880, pt. i, pp. 84–100, map (in Russian).

[3] Ernst Hofmann, Der N. Ural und das Küstengebirge Pae-choi, 4to, Petersb., 1856, II, pp. 207–281, atlas; also A. G. Schrenk, Reise nach dem N.-O. des europäischen Russland, 8vo, Dorpat, 1854, II.

on the Shtchugar; everywhere the stratified series dips to the east, while on the Iltysh forelying folds are known with an inclination to west and east. On the Toell-poss the ancient schists are vertical or dip steeply to the west. Between lat. 63° and 64° a great mass of granitite makes its appearance; this rock predominates when the chain becomes broader, on the eastern side, while towards the west diorite prevails. In the region of curvature granite and gneiss appear to be present over considerable areas. Near the Pareko, on the brow of the bend as it were, at the west foot of the main chain, the talc schists are seen again inclined with reversed dip to the east; a similar dip is shown by the Palaeozoic deposits, situated in front next the western plain, and as well by the whole western border of the north branch, which now bends off to the north-north-east. In 66° 30′, where the direction of the chain passes in a curve from north-north-east to north-east, serpentine and Palaeozoic limestone occur inclined to the east, in lat. 67° and 67° 30′ the Palaeozoic range of Jenga-Pae occurs with a similar inclination, and in the Pae-Putna-jaha in 67° 22′ richly fossiliferous Carboniferous limestone dips in the same direction. Here the mountains, rugged, wall-like, and treeless, rise out of the level tundra. Finally we reach the precipitous *Konstantinov-Kamen*, in 68° 29′. It consists of grey quartzite and schists resembling talc-schist and chlorite schist; on its crest lie blocks of red granular quartzite. The strata dip towards the south-east. On three sides it is surrounded by shallow lakes of the tundra; the sea is only 30 to 35 kilometers distant.

This chain forms the sharply defined northern end of the Ural. At its foot in lat. 68° rises the parallel range of Paemboi, which runs from south-west to north-east. The dip towards the east which prevails over the whole distance observed, from 60° 50′ to 68° 29′, establishes the fact that in the northern as in the central and southern Ural the tangential movement has been so considerable that whole zones have been overturned in the direction of Europe. This inversion, however, is exhibited not on the outer border of the Ural, but rather at those places where the lowest basement beds crop out.—

Beyond the Konstantinov-Kamen a new chain begins. To the north ranges of rocky hills composed of ancient schists rise one after another in the middle of the tundra. They run from east-south-east to west-north-west, and thus take a direction almost perpendicular to that of the Ural. Their height above the tundra scarcely exceeds 150 feet, and they extend as far as the mouth of the Oi-Jaha. To the west of these and of Konstantinov-Kamen there rises a range of more important heights, that of the Jodenei, also running to the west-north-west, and this represents the beginning of the principal range of the chain of *Pae-khoi*. Its direction soon changes from west-north-west and passes more and more to the north-west; its beds become vertical, and it forms the Siwa-Pae in the

Shar (strait) of Jugor, which is here only 3 kilometers broad. The rocks appear to be very much the same.

The Pae-khoi now crosses the strait, traverses the island of Vaigatch, and is continued into *Nova Zembla.* This point has been placed beyond doubt by H. Höfer, the companion of Wilczek [1].

Nova Zembla, says Höfer, is a mountain ridge which runs from 72° to 75° 30′ N. lat. in a south-south-west to north-north-east direction, and attains its greatest height between 73° and 74°. From parallel 75° 30′ the crest-line bends sharply to east-north-east and the range decreases in height; below 72° the terminal ridge bends to the south-east, and then flattens out rather rapidly. The strike of the rocks and the course of the coasts experience the same change of direction as the crest-line. Silurian, Devonian, and Carboniferous limestone are known to occur; augite porphyry is intercalated with the Palaeozoic deposits in the south-west part of the island.

The whole island presents, according to Höfer, a unilateral structure, but since here also the strata along the west coast are said to dip very generally to the east, and since Höfer points out the flattening of the coast towards the interior as particularly characteristic, it appears as though the overfolding of the Ural were also about to find expression in this arc.

The Shar of Jugor, the straits of Kara, and the Shar Matotshkin are thus transverse furrows, like the straits of Gibraltar. They cross a uniform mountain arc, which begins with the Jodenei and ends in the tundra in front of the Konstantinov-Kamen, where it meets in syntaxis the northern Ural and its frontal chain, the Paemboi.—

The principal chain of the Ural, running from north to south, is accompanied on the west by numerous parallel chains which are known as *Parma,* and distinguished as the High Parma, Idschid Parma, and so on. These Parma, as far as they are known, are frontal folds, and mark the dying away of the folding as it proceeds towards the plain; they can only appear in front of such hills as are preceded by a country of the same nature as themselves. If a plateau of alien nature stretched before them, there would be no Parma.

The best proof, however, of the tectonic unity of the folded Ural and the table-land in front of it is furnished by a peculiar feature, which deserves our full attention.

At the Poljudov-Kamen near Tcherdyn, in about lat. 60° N., a long ridge proceeds from the Ural, which extends beyond the arctic circle; this is the *Timan range.* It runs at first to the north-west, rapidly

[1] Graf Wilczek's Nordpolarfahrt im Jahre 1872; H. Höfer, Ueber den Bau Nowaja Semlja's, Petermann's geogr. Mitth., 1874, pp. 297–305; F. Toula, Eine Kohlenkalkfauna von den Barents-Inseln, Sitzungsber. Akad. Wiss. Wien, 1874, LXXI, pp. 527–608, and plate.

diverging from the Ural, then to the north. Together with the Ural it bounds the river basin of the Petchora. At many points it presents outcrops of ancient clay slate; of the Palaeozoic deposits the most widely distributed is the Devonian. The range does not exceed 850 feet in its highest part. Keyserling was the first to recognize its importance; Schrenk and Stukenberg have described it in greater detail [1].

Beyond the arctic circle, near the watershed between the rivers Sula and Wolonga, this long range assumes sharper contours, bends suddenly to the north-west, and reaches the sea in the north-east of the bay of Tchesskaja. In structure it is an anticlinal: its axis consists of granite; this is succeeded on each side by clay slate, then follows some Silurian, and with a broader outcrop Carboniferous; a thick sheet of dolerite is intercalated with the Palaeozoic beds. These rocks form the capes Rumanishni, Barmin, and Tchaizyn. The long spur of Svjatoi Noss is formed by the Carboniferous limestone of the north flank. This is overlaid towards the interior by a patch of the Inoceramus clay of Simbirsk, a witness to the age of this part of the fold. According to the statements of the botanist Ruprecht, the range is continued obliquely through the peninsula, from cape Mikulkin to Kanin Noss [2].

As Stukenberg quite rightly points out, although the long ridge of Timan is nowhere parallel to the Ural, yet the course of the segment which lies beyond the deflexion exactly corresponds to that of the Pae-khoi. We can, indeed, hardly fail to recognize that the deflexion on the Sula may to a certain extent be regarded as a repetition of the syntaxis of the Ural and Pae-khoi, and once more we see reproduced on a large scale lines similar to those presented by the Tertiary land on the Jehlam. On the shores of the Arctic Ocean the fundamental tectonic features are the same as in the sunny plains of the Indus; and the great folded ranges have been developed in a similar manner, here before the upper part of the Jurassic, there after the upper Tertiary. The direction, it is true, differs wholly: while over the whole distance from Asia Minor to the Sunda islands we have recognized a tangential movement, directed, in spite of all local deflexions, mainly to the south; here the movement is directed to the west in the Ural, and in the Pae-khoi even to the north-west.

*Summary.* Five great arcs turned towards the south align themselves

[1] A. Graf Keyserling, Wissenschaftliche Beobachtungen auf einer Reise in d. Petschora-land, 4to, Petersb., 1846, pp. 337-406; Schrenk, op. cit., I, pp. 634-702; A. Stukenberg, Report on the Geological Expedition into the basin of the Petschora and the Timan Tundra, Material. z. Geol. Russlands, 1875, VI, pp. 1-125, map and plate (in Russian).

[2] This I derive from Schrenk and Stukenberg; Ruprecht's publications on this subject only show that in the north-west part of Kanin heights of at most 1,000 feet occur: Beiträge zur Pflanzenkunde des russischen Reiches, II, 1845; Flores Samojed. Cisural., p. 5.

one after the other across the continent; these are the Malay arc, the arc of the Himálaya, the shattered outer arc of the Hindu Kush, the Iranian and the Dinaro-Tauric arc. To these must be added still another, that which, distinguished by somewhat different characters, surrounds the western Mediterranean.

These arcs separate the table-land of North Africa and Arabia, and that of the Indian peninsula, from the folded regions in the north. The Malay arc, and perhaps that of the Himálaya, also surrounds fragments of table-land.

Since these arcs are decidedly more curved towards the south than the folded chains which succeed them on the north, several segments of circles are defined, of which some are highlands, others, however, in-sunken areas, in part covered by the sea. In the arc of the Hindu Kush alone does such considerable constriction take place towards the south as to produce a different conformation of the surface.

Within the table-lands thus marked out regions occur without outlet to the sea, as, for instance, that within the arc of the Himálaya, of the Iranian arc, and of the eastern half of the Dinaro-Tauric range. The extent of these closed basins diminishes considerably towards the west.

The Malay arc and its 'backland' have been partly broken down and sunken in; the same is true of the central part of the Dinaro-Tauric arc. In both cases there appear within the sunken areas islands with strange chiragratic forms, such as the Celebes and Halmahera, Chalcidyce and Morea. We know from Neumayr and Burgerstein that each of the three peninsulas of Chalcidyce possesses a different structure: Hagian Oros is an anticlinal of crystalline schists and limestone broken across transversely; Longos is formed of gneiss, Cassandra of Tertiary deposits. This shows that the outlines are independent of the structure of the land, and have been determined by subsidence.

On the outer border of most of these arcs, from Burma as far as the Mediterranean, 'middle' Tertiary strata are met with either folded or overfolded. On the coast of Makrán more recent marine strata lie unconformably and horizontal.—

The folds of the Thian-shan strike to the north of these arcs towards Europe. The Paropamisus runs through the Caucasus to the Balkans and Carpathians; violent bendings of the strike occur; the folding is here no longer directed to the south but to the north; it appears as though the arc of the Carpathians had been driven out northwards over the Russian Platform and the Sudetes.

The Nura-tau is continued through Sheich Djeli as far as Mangishlak, and towards the Donetz.

This arrangement is clearly marked in the form of the Caspian sea, for its outline on the south is determined by the Albourz, i. e. the Iranian arc;

the peninsulas of Krasnovodsk and Apsheron correspond to the course of the first of the just-mentioned branches of the Thian-shan, that of the Mangishlak to the second of these branches. The Caspian sea, as we have seen on an earlier page, is a survival from extremely ancient times, while the Pontus is a recent inbreak, and it is not altogether without significance that the outline of the Caspian gives expression to the course of the folds, while that of the Pontus does not. The Aegean sea has broken in across the folds of Greece; the outer arcs, however, exhibit themselves in the outlines of Crete and Cyprus.

In the outer border of the Alps and the Carpathians middle Tertiary beds bear witness to the fact that the tangential movements were continued into the period they indicate, and this is also the case further to the east. In Slavonia even the Paludina beds of the Levantine stage are upturned; in Kertch the Sarmatian, and probably the Pontic deposits also, take part in the folding; in the eastern Caucasus Sarmatian beds occur at very considerable heights and form the folds north of Vladikavkas. Even much further in the east, however, on the south border of the Thian-shan, towards the depression of Kashgar, we know from Stoliczka of the presence with reversed dip of the *Artush series*, probably of middle Tertiary age; and Muschketoff has met with similar Tertiary deposits, as he has had the kindness to inform me, in the Thian-shan, at heights of from 10,000 to 11,000 feet, on the Tchatyr-Kul, for example, and near the pass of Taimurum. They extend in beds of red conglomerate and sandstone across the Alai and Suek towards Fergana and Turkestan.—

Thus we see that since the middle Tertiary period, and up to still more recent times, important tangential movements have taken place, and have thrown into folds a sea-bottom which extended through the middle of Europe and Asia, while the table-land in the south has remained as unaffected by these movements as the horsts and ancient fragments of central and western Europe. The latter, it is true, have also been moved to the north-west, north, or north-east, and this movement finds expression with particular clearness in the Belgian coal-fields; but the folding of the Alps was accomplished independently, and is checked or deflected by these masses.

Different again is the behaviour of the isolated mountain segment of Matchin on the Danube. The upper Jurassic and the Cenomanian lie horizontally on its upturned strata. No connexion with the long folds we have just mentioned is to be recognized.

Equally different in age and direction are the Ural, together with the Pae-khoi, as far as Vaigatz and Nova Zembla, and the Timan range with the peninsula of Kanin. Here, too, syntactic arcs are present, but the upper Jurassic lies horizontally on the slopes of the Ural, and similarly the Cenomanian on the heights of the Mugodjars.

# CHAPTER IX

## SOUTH AMERICA

The Brazilian mass. The Argentine chains. The Andes of Bolivia and Chili. The coast Cordilleras and Patagonia. Peru. Ecuador. North Granada and Venezuela. Summary.

*The Brazilian mass.* Let us now approach the broad continent of South America from the Atlantic ocean.

The islands lying off its coasts are but few, and on those volcanic rocks predominate. *Fernando Noronha* consists of phonolite and basalt; even on the *Abrolhos* a volcanic rock, probably basaltic, occurs intercalated with beds which presumably belong to the Cretaceous system. On the continent, however, with the exception of a few extrusions of igneous rocks, which at the latest extend into the Cretaceous, no trace of recent eruptive activity is anywhere to be seen.

Since the opening decades of the last century, when a more detailed knowledge of the structure of Brazil was furnished by Austrian miners and travellers, geological observations have been multiplied in this vast region, and the efforts of Hartt, too early lost to science, and those of his successors, have made us acquainted with the outlines of its structure [1].

We will land in the famous bay of Rio, then, after a hasty glance at the interior, approach the provinces on the east coast; after this we will consider the structure of the great basin of the Amazon, and, finally, passing beyond the boundaries of Brazil, that of Guayana as far as the Orinoco. Here on the Apuré and Orinoco we reach the northern limit of a great uniformly constructed portion of the earth's crust, which may be designated the *Brazilian mass*.

Rio de Janeiro is surrounded by the oldest rocks of the continent. Far to the south, along the whole of its course through the province of São Paolo, the Serra do Mar breaks off abruptly on the side facing the sea. The Parahyba collects its waters in a longitudinal valley parallel to the coast, and, then cutting across the strike of the ancient mountains of gneiss, finally reaches the sea; but on the other side of this valley the waters flow inland and the watershed of the vast continent lies close to its coast. It is as though on leaving the sea we had climbed the edge of a basin, as in the parallel case of the Ghâts in India.

Further towards the interior, in Serra Mantiqueira and far away to the

[1] C. F. Hartt, Geology and Physical Geography of Brazil, 8vo, Boston, 1870.

north and north-west, a great variety of rocks is met with, unfossiliferous schists and quartzites, hornblende and talc rocks, granular limestone, and the itacolumite series, which many geologists regard as the upper subdivision of the Archaean succession, but others, including Hartt, as in part at least lower Silurian [1].

On these rest great horizontal masses of Devonian and Carboniferous deposits, and then, finally, a thick covering of unfossiliferous sandstone broken up into table mountains.

The province of Paraná to the south of Rio affords, according to the description of Orville Derby, a good example of this succession of rocks. On account of the rare beauty of its scenery, the Serra do Mar is here known as the Serra Graciosa. It rises abruptly from the sea, running east-north-east, with steeply inclined strata. It consists of granite, porphyritic rocks, and schistose gneiss, associated with very ancient eruptive rocks. Further to the west, we meet with serpentine and marble, talc-schists, quartzites and itacolumite, and all the members characteristic of the more recent series, which proceed through Bahia and Minas Geraes, and probably also through Rio Grande do Sul. About 50 kilometers west of Curia-tyba a steep cliff runs transversely across the province of Paraná from north to south. Its lower part consists of the same later Archaean or lower Silurian series, in steeply inclined beds; the upper part, on the other hand, of horizontal beds of coarse white sandstone, which is traversed by numerous dykes of greenstone. Still further to the west shales are intercalated containing Devonian fossils. On the Irahy a siliceous limestone of Devonian age also appears. The Carboniferous system is probably also represented. The surface of the ground sinks a little, and we encounter a second cliff, the Serra de Esperança, with a height of 1,040 meters above the sea. This runs transversely across the whole province. The lower part consists of soft red sandstone, the upper of a sheet of amygdaloid, 100 meters thick or over. This great covering, which is probably of Mesozoic age, appears to approach the Serro do Mar on the south and to be very widely distributed in Uruguay [2].

Exposures of Devonian and Carboniferous are continued, on the one hand, through Rio Grande do Sul, on the other through São Paolo; in the Maranhão and Matto Grosso, on the Guaporé, and on the upper Paraguay, Carboniferous strata are said to occur. Horizontal, or at least very gently inclined beds of unfossiliferous sandstone appear in Minas Geraes and São Paolo, as the remnants of a once-continuous covering of sandstone,

[1] An attempt to determine these formations still further and to compare them with the mountains of North America has been made by W. O. Crosby, On the Age and Succession of the Crystalline Formations of Guiana and Brazil, Proc. Boston Soc. Nat. Hist., XX, 1880, pp. 480-497.

[2] Orville A. Derby, The Geology of the Diamantiferous Region of the Province of Paraná, Brazil; Proc. Am. Phil. Soc., Philadelphia, 1879, XVIII, pp. 251-258.

now broken up into isolated Chapadas, i. e. table mountains. They attain heights of 2,000 to 3,000 feet above the sea, become broader towards Matto Grosso, and then unite between the river Tocantins and Rio São Francesco, to form a great continuous sheet, from which the Archaean rocks often project only in the form of islands; they reach the north coast through the provinces of Piauhy and Ceará.

The age of this sheet of sandstone is not known; it may indeed include deposits of different ages.—

At some places in the eastern provinces, as for instance near Estancia in Sergipe, and in the mountains above Rio de Contas, we again recognize the red sandstone and marl of Mesozoic age, already met with on the Serra de Esperança in Paraná. It is compared by American geologists to the Trias of the eastern United States; it also recalls the similar deposits beneath the transgressive Cretaceous on the Spanish Meseta.

On the east coast, near Camamú, south of Bahia, there occurs resting on gneiss a friable rock, rich in petroleum, which is called *turba*. In Bahia the lowest bed immediately above the gneiss is a fresh-water deposit with Crocodilus, Melania, Vivipara, Unio, and Estheria; not far from Bahia a bone bed, with remains of Dinosaurus and Crocodilus, occurs on the same horizon. These beds, to which perhaps the turba of Camamú also belongs, are regarded as the equivalents of the Wealden or Neocomian. Above them lie marine beds of middle Cretaceous age, with Buchiceras; then upper Cretaceous with Inoceramus, and at the summit a deposit with Mosasaurus. According to Hartt marine transgressive beds of the Cretaceous system occur in Piauhy, Ceara, Parahyba do Norte, Pernambuco, Alagoas, and south of Sergipe as far as Bahia, probably indeed as far as the Abrolhos [1]. It would appear that these Cretaceous sediments underlie the whole basin of the Amazon. The most southerly locality in which Cretaceous fossils are found in the east is Bahia.

Very far to the west, in the Argentine Republic, we shall again meet with fresh-water beds containing Melania and bearing petroleum; these deposits crop out from beneath the west edge of the plateau of Matto Grosso, and it is believed that they correspond to those of Bahia. Such a remarkably wide distribution is certainly hard to understand.—

We now enter the basin of the *Amazon*, and again follow a very instructive description by Orville Derby, who has collected together the results of previous investigations in this extensive depression [2].

[1] S. Allport, On the Discovery of some Fossil Remains near Bahia, South America, Quart. Journ. Geol. Soc., 1860, XVI, pp. 263-268; Hartt, op. cit., pp. 263, 346, 355, 556 *et passim*.

[2] Orville A. Derby, Contribuições para a geologia da região do Baixo Amazonas, Arch. do Mus. Nac. do Rio de Janeiro, 1877, II, pp. 77-104 (an English translation is given in the Proc. Am. Phil. Soc., Philadelphia, 1879, XVIII, pp. 155-178); also Hartt, Contri-

So low does this basin lie that, far in the west, even near the eastern slope of the Bolivian Andes, on the upper course of the Purús, Chandless met with no height of more than 1,088 feet. From north and south the ancient rocks advance to the great river. The oldest visible members probably belong to the lower Silurian series. From Guayana they are exposed along a line which begins on the Atlantic coast in about lat. 1° N. and extends nearly as far as the confluence of the Rio Branco with the Rio Negro in lat. 1°–2° S. In the south the same rocks give rise to the rapids of the southern tributaries, and the northern limit of the areas over which they are exposed crosses the Tocantins in lat. 3°–4°, the Tapajos in 4°–5°, and the Madeira in 8°–9° S. The Madeira appears for a long distance to form the western boundary of their visible extension.

To the north of the Amazon a fairly broad girdle of upper Silurian meets these older rocks in the valleys of the Trombetas, Curuá, and Maecurú, and probably along the whole length of the line. These beds correspond to the Medina sandstone of the Niagara group in North America. On the south side of the Amazon this zone is not known; possibly it only awaits discovery.

The next zone, broader than the Silurian, belongs to the Devonian and is divisible into several groups. It is well developed to the north of the river, along the Silurian zone, and to the west as far as the Uatumá, a little river between the Trombetas and the Rio Negro. On the south side only traces of this zone have been recognized, but it is exposed in the midst of the alluvial land of the Amazon, to the west of Monte Alegre, as the disintegrated outcrop of an anticlinal which strikes from east to west.

The Carboniferous deposits occupy a much larger area. On the north side of the Amazon they extend to the east at least as far as Prainha, they reach the river bed itself near Alemguer, and stretch to the west at least as far as Uatumá. In the south they extend probably from the Tocantins to the Madeira, and are particularly well exposed on the Tapajos.

The Palaeozoic deposits thus form a symmetrical basin, the centre of which is occupied by Carboniferous beds; and it is only the anticlinal near Monte Alegre which brings Devonian deposits into view in the alluvial land of the Amazon.—

A very remarkable gap in the series now occurs. The next oldest deposit, above the preceding, which has yet been recognized in this vast basin, is a coarse sandstone. From the vicinity of Ereré and as far as Monte Alegre it lies on Devonian strata and contains plant remains, which are usually assigned to the Cretaceous period. Still further up Cretaceous

butions to the Geology and Physical Geography of the lower Amazonas, Bull. Buffalo Soc. Nat. Hist. 1874. I, pp. 201-235; Rathbun, The Devonian Brachiopoda of the Province of Pará, Brazil, Proc. Boston Soc. Nat. Hist., 1879, XX, pp. 14-39.

deposits are largely developed; west of the Madeira, on the Aquiri, in the region of the Purús, remains of Mosasaurus and tortoises have been found in them.

Thus during Cretaceous times the region of the Amazon appears to have formed a vast bay bounded by Palaeozoic rocks. Near Ereré eruptive rocks are intruded into the Cretaceous beds.

Beds of variegated sandstone represent the later part of the Tertiary period, and are especially well displayed on the lower course of the river between Prainha and Almeirim. At the base of these deposits a blue clay containing fossil shells is found at Pebas in Peru, near the mouth of the Ambayacú. Boettger, who has examined this fauna, which has brackish water characters, explains the beds of Pebas, on account of their peculiar facies, as 'formations of the lower course of the ancient Marañon, dating back certainly from the Oligocene, and perhaps even from the Eocene period [1].'

All that is so far known of the geological structure of the country north of the basin of the Amazon shows it to be a repetition of the regions to the south. Archaean rocks, among which granite may be specially mentioned, form, it appears, the whole foundation; they are still visible even as far north as the confluence of the Caroni with the Orinoco. Mighty masses of horizontally stratified sandstone resting directly on this foundation are described by Sawkins in British Guiana, between lat. 4° and 6° N. According to the accounts of the same observer a gigantic table mountain of this kind, traversed by numerous dykes of greenstone, forms the horizontal summit of the Roraima, which rises on the Venezuelan frontier, 7,500 feet high and surrounded by steep cliffs [2].

Beyond the Orinoco, however, there lies, as we shall see directly, a land of different structure.—

*The Argentine Chains.* The high ranges of South America consist of two parts, which enter into syntaxis at an obtuse angle, in the south of Peru and in Bolivia east of the bay of Arica. In making a detailed examination of their structure we will begin with the southern part and in the Argentine Republic, where under Burmeister's leadership a school of investigators has grown up, and research is more advanced than in any other part of the great mountain region which extends from the Caribbean sea to cape Horn.

From the Bolivian highland several parallel chains run from north to south into the west of the Argentine Republic. The most westerly of

[1] O. Boettger, Die Tertiärfauna von Pebas am oberen Marañon; Jahrb. geol. Reichsanst., Wien, 1878, XXVIII, p. 503.

[2] J. G. Sawkins, Geological Observations on British Guiana; Quart. Journ. Geol. Soc., 1871, XXVII, pp. 419–433; also Atwood, A Contribution to South American Geology, op. cit., 1879, XXXV, pp. 582–588. H. Whitely has published his views on the lofty table mountain Roraima and its neighbour Kukenam in Proc. Geogr. Soc. Lond., 1884, pp. 458 and 461.

these align themselves along the principal chain of the Andes, the most easterly are surrounded by the Pampas. Several observers however, and among them Stelzner, who has contributed so much to our knowledge of these regions, have pointed out that the ranges, which rise much further in the south-east, between Buenos Ayres and Bahia Blanca, and run to the south-east, must also be included among the west Argentine sierras, as is shown by the correspondence between their rocks [1].

Thus our first glance at the Andes leads us to the east, and towards Cabo Corrientes.—

The most northerly part of the Argentine chains, extending approximately from lat. 22° to 25° S. through the provinces of Salta and Jujuy, has been studied by Brackebusch. This is the region of the head-waters of the Rio Vermejo. To the west, in the interior of the high ranges, it is followed by a region having no outlet, the Salinas de la Puna. The usual cartographic representations of this country are very erroneous, and according to Brackebusch, whom I here follow, the position of Oran must be carried probably a whole degree further to the west [2].

From the Gran Chaco, near the east foot of this northern range, there rises first a thick series of beds, which are characterized by their richness in petroleum and rock-salt. They consist of variegated sandstone with dolomite and gypsum; contain fish remains, and in some places a great number of little gastropods; *Chemnitzia (Melania) Potosensis*, d'Orb., appears in crowds. Opinions as to the age of these beds are widely divergent; Brackebusch places them between the Jurassic and Cretaceous systems, and observes that the quartz porphyry, which crops out here and there in the provinces of Salta and Jujuy, is always found in association with the variegated sandstone [3].

These petroleum-bearing deposits have a remarkably wide distribution; they probably form the subsoil of the Gran Chaco, and extend far to north and south on the eastern border of the mountains; Brackebusch is inclined to connect them with the petroleum-bearing and fresh-water beds already mentioned as occurring on the east coast near Bahia.

These deposits, however, not only constitute the subsoil of the plains; they have also shared in the formation of the mountain ranges, and appear both at the bottom of the valleys between the parallel ranges, as long meridional bands, which advance far towards Bolivia, and also

[1] A. Stelzner in R. Napp, Die argentinische Republik, 8vo, Buenos Aires, 1876, p. 71. The course of these chains may be seen on the map in H. Burmeister, Die südamerikan. Republiken Argentina, Chile, Paraguay und Uruguay, Petermann's geog. Mitth., Ergänzungsheft 39, 1875.

[2] L. Brackebusch, Estudio sobre la formacion petrolif. de Jujuy, Bol. Acad. nac. Córdoba, 1883, V, pp. 137–184, and by the same, Viaje á la provincia de Jujuy, op. cit., pp. 185–252, map.

[3] Brackebusch, op. cit., p. 181; for Aconquija see also Kuss, Notes sur les filons de quartz aurifères de l'Atajo, Ann. d. Mines, 1884, XLVIII, pp. 341 et seq.

at a great height on the chains themselves, at about 5,000 meters for instance on the Sierra de Zenta, which bounds the great longitudinal valley of Humahuaca on the east.

The chains consist principally of quartzite, shales, and greywacke, in steeply upturned beds which contain fossils of the primordial fauna and of the lower Silurian. The principal band of Silurian rocks runs from the great mountains of Bolivia, in the provinces of Potosí and Tarija, down through Jujuy and Salta, and finally forms the not very high Sierra de San Javier on the east side of the Nevado de Aconquija, west of the town of Tucuman. Its most important parallel ranges to the west are: the Sierra del Aguilar, which, rising from the plain of Puna to a height of 5,300 meters, brings to light the granitic basement, and next the Sierra de Cochinocha and Sierra de Cabalonga, abounding in mines, both of which run towards Bolivia; the latter range is surrounded by the great trachyte masses which form the frontier mountains. The Nevado de Aconquija consists of granite and gneiss, and is continued northwards between the Silurian chains; its spurs appear on the west side of the Salinas de la Puna and, as already mentioned, at the foot of the Sierra del Aguilar.

On the east side of the principal chain Silurian ranges are also present; one of these, the most easterly, deviates from the general parallelism, is deflected to the north-north-east, forms the Sierra de Santa Barbara and Sierra de Maiz Gordo, and dips beneath the Gran Chaco before it reaches the Rio Vermejo.

The Silurian bands are traversed, especially in the west, by very numerous dykes and bosses of trachyte.—

We know from Stelzner that these ranges are continued far to the south, even down to latitude 33° S.[1] They are long and narrow, often rugged and of considerable height, and deviate but little from a meridional direction. On the west they are generally somewhat more closely crowded together, on the east they stand further apart. The dip of the beds is steep. A part of these chains consists of crystalline schists, gneiss, and granite; extensive extrusions of porphyritic rocks, trachyte, and, more rarely, basalt are also present. To the west of San Juan a long band of limestone runs from north to south. It is of lower Silurian age, as Kayser has shown from an examination of the specimens collected by Stelzner along its outcrop for a distance of 150 kilometers. East of the Sierra Famatina runs a parallel chain, likewise of lower Silurian age[2].

On the eastern slope of the same sierra and of its continuation to the south, as well as at several places in the provinces of La Rioja, San Juan,

[1] Stelzner, Neues Jahrb. für Min., 1872, pp. 193-198, 630-636; 1873, pp. 726-744.

[2] E. Kayser, Ueber primordiale und untersilurische Fossilien aus der argentinischen Republik (also under the title Beiträge zur Geologie und Palaeontologie der argentinischen Republik, edited by A. Stelzner); Palaeontographica, Supplem. 1876, III, pp. 1-5.

and Mendoza, bituminous sandstone and shales occur in long meridional bands. These are the continuation of the petroleum-bearing deposits of Jujuy and Salta, but here they are of Rhaetic age [1], as is shown by included plant remains.

In the sierras which occur further to the east, between San Luis and Cordoba, Silurian fossils have not yet been found. The most easterly chains, and those in particular which rise near the city of Cordoba, namely, the Sierras Ischilin, Achale or de Cordoba, and Cerezuela, consist solely of gneiss, Archaean schists, marble, and intrusions of granite and trachyte [2].

We now reach those chains of the province of Buenos Ayres which run to south-east or east-south-east, and form part of Burmeister's 'system of the southern Pampas.' There are here two chains, the *Sierra Tandil*, which forms the Cabo Corrientes, and to the south of this the loftier *Sierra de la Ventana*, which reaches a height of 1,030 meters. Parchappe, the companion of d'Orbigny, and Darwin have visited them, and subsequently Heusser and Claraz, but it is only since the description by Doering that it has become possible to give an account of their structure in detail [3].

Both chains consist of the same rocks, and both are monoclinals flexed in the same direction; the dip of the beds is to the south-west, and the oldest members are visible on the north-east side.

The north-eastern border of the Sierra Tandil is formed of granite; this is followed by gneiss dipping somewhat steeply to the south-west, and on this there rests unconformably, and with a much gentler inclination, a series of talc schists, clay slate, dolomite, and well-bedded quartzite; the petrographical correspondence of this series with the Silurian deposits of the meridional chains of the west Argentine is recognized by all the authorities best acquainted with the country. The south-eastern declivity of the sierra is a very gentle slope; sometimes indeed the quartzite lies nearly horizontal, and is broken up by erosion into table mountains.

The second range consists of several parts, generally comprised under the name of the Sierra de la Ventana. The first part is the long Sierra de Cura-Malal, which comes from the west-north-west; it is continued into the chain of Pilla-Huincó, to the east-south-east; where these chains unite the loftier Sierra de la Ventana branches off at a very acute angle, and

[1] H. B. Geinitz, Ueber rhätische Pflanzen- und Thierreste in den argentinischen Provinzen La Rioja, S. Juan und Mendoza, op. cit.

[2] Brackebusch, Informe sobre un viaje geológico por las sierras de Córdoba y de S. Luis, Bol. Acad. Córd., 1876, II, pp. 167–216; Stelzner, in Napp, Argentinische Republik, pp. 71 et seq.; also republished in part in O. Wien, Die Sierra von Córdoba, Zeitschr. f. allg. Erdk., Berlin, 1882, XVII, p. 57 et seq., map.

[3] Informe oficial de la comision científica agregada á la expedicion al Rio Negro bajo l'órd. del general D. Julio A. Roca, 4to, Buenos Aires, 1883; III, Geol., por el Dr. Ad. Doering, pp. 299–400. For parts of the Sierra Tandil cf. also Holmberg, Act. Acad. Córd., 1884, V, pp. 28–30 and 58.

runs somewhat more to the south-east. The Sierra de Pilla-Huincó consists, so far as it is known, of gneiss; both the other chains are quartzite. This, however, is much more steeply upturned than in the Sierra Tandil, often even standing vertical, and the jagged sharp edges of the fissured walls of quartzite present a curious contrast to the vast plain of the Pampas, out of which they rise.

The suggestion that these sierras running to the south-east are merely the deflected continuation of the meridional sierras, which are composed of the same rocks, receives confirmation from the fact that further to the west, on the banks of the Chadí-Leuvú (Rio Salado), granite and porphyry project from the plain, and are continued to all appearance, according to Doering, by a series of isolated bosses as far as the pre-Cordilleras, i.e. the eastern collateral chains of the Andes. This series runs from the Sierra de Chorque-Mahuida, which rises in 38° 5′ lat. S., on the north side of the Rio Colorado, about 100 meters above the plain, is continued to the Sierra de Lihué-Calel, about 60 to 70 kilometers to the north-north-west, near the great Lago Urre Lauquen, then to the Sierra de Luan-Mahuida, which lies 50 kilometers further to the north-north-west, and by other bosses to the Sierras of Luan-có and Auca-Mahuida, which are connected with the lofty meridional chains of the pre-Cordilleras.

Still further on the east coast, near San Antonio, in the Bahia de San Matias, an isolated rock of porphyry rises aloft.

The Patagonian table-land is formed of horizontal beds of Tertiary age, and of others even more recent. Far to the south, at the extremity of the continent, the bending of the Andes is completed in Staten island. This deflexion takes place in precisely the same direction as that of the meridional sierras of the west Argentine towards the Sierra Tandil and Cabo Corrientes, and towards the Sierra de la Ventana and the bosses of Choique-Mahuida, which is indicated by a correspondence of features already considered. This concurrence in direction shows how general the movements must have been, and we are led to the conclusion that the branches of the Andes, on the south and south-east, diverge from one another in the same way as the western branches of the Thian-shan.

Over the wide plains formed by this virgation recent sediments extend with approximately horizontal bedding. Even from Sante Maria in Catamarca (about lat. 26° S.), Stelzner mentions sandstone with bivalves as a possible indication of a marine Tertiary deposit[1].

The Sierra de Maiz Gordo (lat. 25° to 24° S.), which runs to the north-north-east in the province of Salta, may perhaps indicate a similar virgation in the opposite direction.

*The Andes of Bolivia and Chili.* The chains of the Andes run in the south of Peru and Bolivia to the south-east, in Chili to the south, and are

[1] Stelzner, Neues Jahrb. f. Min., 1873, p. 728.

deflected in Patagonia first to the south-east and then to due east, in the direction of Staten island. The course of the coast follows these changes of direction very closely, and the bay of Arica, as well as the outline of the southernmost part of America, curved so curiously to the east, owes its significance to this fact.

In the south of Peru there are two very high chains and several other parallel chains of less importance. Of the two principal chains, the western, which forms the watershed towards the Atlantic Ocean, is known as the Cordillera of the Andes, in the restricted sense, although the eastern Cordillera, to which Illimani and Illampu belong, attains a greater altitude, especially in its southern part. This chain is traversed by transverse valleys, which open towards the east.

In Chili the Cordillera consists only of one principal chain, which, as we shall see directly, must be regarded as the continuation of the western chain of Peru. But west of this, next the sea, some very peculiar features may be observed. Close to the coast run a number of independent mountain segments, for which we will employ the general term *Coast Cordilleras*. Between these and the eastern slope of the Andes there lies in the north the desert of Atacama, further to the south the great longitudinal valley of Chili; still further to the south again, along the bay of Corcovado and the Moraleda channel, the principal chain of the Cordilleras disappears.

If we now compare the features represented in Domeyko's orographic description of the province of Aconcagua with those obtained by the hydrographic surveys of Captain Simpson in the south, we discover the following relations. In the province of Aconcagua a series of deep valleys run from the Andes, across the Coast Cordilleras, directly to the sea; but on the summit of the ridges which separate these transverse valleys is a series of shallow saddle-like hollows, which occur at a nearly uniform height of 1,200 to 1,300 meters, and along a line running from north to south. The continuation of this line extends through the great longitudinal valley of Chili. We might almost feel inclined to suspect that, in Aconcagua, a younger system of transverse valleys has been superposed on an older longitudinal system, so that the position of the older longitudinal valley can no longer be recognized, except by the hollows which cross the summit of the transverse ridges. In the south the case is modified. The sea has entered into the prolongation of the longitudinal valley, and the transverse valleys, steeply inclined and filled with glaciers, closely correspond in position with the straits which separate Chiloë and the various islands on the south one from another, as though the system of transverse valleys, which here also once crossed the longitudinal valley, had like it been submerged [1].—

[1] J. Domeyko, Estudio del relieve, &c., Anal. Univ. Chile, 1875, XLVII, pp. 51, 60; E. M. Simpson, Esploracion hidrográfica de la Chacabuco, op. cit., 1872, p. 427, and

The Coast Cordilleras are represented already in Peru by some fragments occurring along the coast, but these do not become continuous till some distance further south. In Chili they form chains of some importance, and are continued into Chiloë, the Chonos, and other islands. They form finally the whole terminal part of the South American ranges. The sudden interruptions of the coast line by rectangular projections are very peculiar; they occur also at Morro de Mejillones, south of Coquimbo, and in the bays of Talcahuano and Arauco.—

The syntaxis of the chains in the bay of Arica takes place very gradually; zone by zone the mountains pass from the south-easterly direction of Peru into the meridional direction of Chili. This may already be recognized in the most ancient of the sedimentary systems.

The lofty eastern Cordillera of South Peru and Bolivia, the chain of the *Illimani* and *Illampu*, with summits rising to 6,400 meters, consists, as D. Forbes has shown, of thick Palaeozoic deposits, dipping to south-west: at its north-east foot the underlying granite is exposed [1]. Strata of Silurian age form these colossal masses, and nearly all the great ranges as well, which run from the north of Cuzco through the Cordilleras of Carabaja and Apollobamba towards the Argentine frontier. We have already encountered the prolongation of this great Silurian zone, in the west of the Argentine Republic, and in numerous meridional chains which extend through the provinces of Jujuy, Salta, Tucuman, Catamarca, Rioja, up to Mendoza.

In Peru and Bolivia the Silurian is followed on the south-west by a Devonian zone, and this is overlaid in the neighbourhood of Lake Titicaca by folded Carboniferous limestone. The distribution of this limestone is very extensive; it has been observed by Raimondi far towards the north-west, near Huanta, and by Toula in the south-east to within about 10 geographical miles of Cochabamba [2].

In the Andes of Bolivia the next member, which immediately succeeds the Carboniferous limestone, is a very thick series of red sandstone and conglomerate, in many places rich in copper, sometimes associated with gypsum, and frequently, indeed nearly always, accompanied by porphyry. The only organic remains as yet furnished by this series are silicified trunks of coniferous trees, badly preserved leaves, and traces of reptiles. It has been placed on the same horizon as the Rothliegende of Europe; a reference

Memor. de la Marina, 1872, p. 379. This peculiar phenomenon will be again discussed in a later passage.

[1] D. Forbes, On the Geology of Bolivia and Southern Peru, Quart. Journ. Geol. Soc., 1861, XVII, pp. 7-62, pl. i-iii; J. W. Salter, Fossils from the High Andes, collected by D. Forbes, op. cit., pp. 62-73, pl. iv, v.

[2] A. Raimondi, Letter to Gabb, Proc. Californ. Acad., 1867, III, pp. 359, 360; F. Toula, Ueber einige Fossilien des Kohlenkalkes von Bolivia, Sitzungsber. Acad. Wiss. Wien, 1869, LIX, pp. 433-444.

suggested by many indications, but we shall soon encounter in Chili rocks of the same petrographical character which belong to a much more recent period.

In south Peru this Rothliegende is the most recent member of the eastern Cordillera and at the same time the basement of the western Cordillera. The latter forms the watershed, and is termed, but in this region only, the *Cordillera of the Andes.*

The western Cordillera is formed of a variety of Mesozoic deposits, principally Jurassic and lower Cretaceous. It is crowned by mighty volcanos, superposed upon it as foreign structures.

Just as the eastern Palaeozoic chains of Bolivia correspond in constitution to the chains of the Argentine Republic, so the western Cordillera of Bolivia corresponds in the south to the principal chain of the Chilian Cordilleras. The oldest fossils furnished by the Bolivian Cordillera are a species of Avicula, and some plant remains of Rhaetic age. The marine deposits, which next succeed, belong to the Lias, and the series is continued with a marine character up to the middle or upper Cretaceous. Thus a zone of Jurassic and Cretaceous is present, which extends through Peru, Bolivia, and Chili as far as lat. 35° S., and perhaps even still further [1].

On this zone, in the south as in the north, the volcanos are superposed. Their ashes and flows have covered a very large part of the Mesozoic series. The Jurassic and Cretaceous limestones are often traversed by trachyte or other eruptive rocks, and the richest deposits of silver are associated with these intrusions.

The line of volcanos runs across the north of Bolivia. In lat. 24° 45′ S. Llullaico rises to a height of 6,175 meters. Then follow to the south the volcanos del Chaco, de Doña Inez, del Azufre, and the series terminates in about lat. 26° S. Through eight degrees of latitude, as far as 34°, recent volcanos, according to Pissis, are absent, but still volcanic rocks occur in this interval; thus they are found, according to Güssfeldt's investigations, at a great height on Aconcagua; and it is an open question whether this mountain, 6,970 meters in height, does not bear a crater [2].

[1] I. Domeyko, Sur la géologie du Chili, et particulièrement 1° Sur le terrain de porphyres stratifiés dans les Cordillères; 2° Sur le rapport qui existe entre les filons métallifères et les terrains du système des Andes, Ann. des Mines, 1846, 4e sér., IX, pp. 3–34, pl. i and ii; and by the same, Sur la constitution géologique du Chili, op. cit., pp. 365–540, pl. iv–vii, *et passim*; C. Darwin, Geological Observations on the Volcanic Islands and parts of South America, 2nd ed., 1876, in particular pp. 470–603; A. Pissis, Recherches sur les systèmes de soulèvement de l'Amérique du Sud, Ann. des Mines, 1856, 5e sér., IX, pp. 81–146, pl. iii, iv; by the same, Sur la constitution géologique de la chaîne des Andes entre le 16e et le 53e degré de lat. sud, op. cit., 1873, 7e sér., III, pp. 402–426, pl. ix, x; E. Concha y Toro, Analogías entre la formacion geológica de Chile y de Bolivia, Anal. Univ. Chile, 1872, pp. 538–555; and A. Rémond de Corbineau, Lista alfabética de las fósiles que se han hallado en Chile, &c., op. cit., 1867, pp. 99–141.

[2] P. Güssfeldt, Der Vulcan Aconcagua von NNW., Zeitschr. deutsch. u. öst. Alpenver., 1884, pp. 404–406, pl., and Sitzungsber. Akad. Wiss. Berlin, 1884, p. 922.

On the western slope and at the foot of the volcanic chain there lie in the north the Salinas de Atacama and de Punta Negra, the Lagune del Pedernal, and others, and to the west of these the Jurassic and lower Cretaceous limestone zone of the Andes makes its appearance, forming the eastern border of the desert of Atacama. The zone extends to the south through Caracoles, the Cordon de Varas, beneath Doña Inez, and the Lagune del Pedernal. In front of the Jurassic chain the desert of Atacama slopes down to the sea and to the Coast Cordillera, but isolated patches of red sandstone occur, according to Pissis, as far as Paposo close on the coast, and isolated outcrops of Mesozoic limestone as far as the eastern border of the Coast Cordillera, especially to the east and north-east of Chañaral[1].

When Burmeister, starting from Copocovana, in the north of the Argentine Republic (lat. 28° S.), crossed the end of the Bolivian highland from the northern spurs of the Serra Famatina, he came upon red sandstone with gypsum accompanied by porphyry and trachyte near the frontier of Chili, and finally, near Juntas on the Rio Copiapó, the mighty Jurassic limestone zone, which extends to the south from the eastern border of the desert of Atacama[2].

The Jurassic system has been recognized in many localities extending in a long series down the Andes as far as the region in which Aconcagua is situated. In this locality also the mountains, with the exception of the most easterly parts, consist of rocks which are not older than the Permian, or, judging by Steinmann's results in the south, not older than the Rhaetic period. Pissis has shown that on the western slope of the Andes the richly fossiliferous Jurassic limestone extends through the province of Aconcagua nearly as far as San Felipe and Santa Rosa de los Andes, and that a Jurassic outcrop stretches along the eastern slope of the high range of the Cerro de la Ramada to the north of Aconcagua down to the Cerro del Juncal to the south of it[3].

The summit of Aconcagua itself lies somewhat to the east, outside the principal range, and consists, as we have said, of volcanic rocks.

It is this Jurassic band which Stelzner met with in two places, north of Aconcagua, in the pass of los Patos (Espinazito) near the Cerro de la

[1] A. Pissis, El desierto de Atacama, su jeolojia, sus producciones i minerales, Anal. Univ. Chile, 1877, pp. 573–597; geological map of Atacama by Villanueva, op. cit., 1878; F. A. Moesta, Ueber das Vorkommen der Chlor-, Brom- und Jodverbindungen des Silbers in der Natur, ein Beitrag zur Kenntniss der geolog. und bergbaul. Verhältnisse von Nord-Chile, gr. 8vo, Marburg, 1870; likewise G. Steinmann, Zur Kenntniss der Jura- und Kreideformation von Caracoles (Bolivia), Neues Jahrb. f. Min., &c., 1881, I. Beil.-Band, pp. 239–301, pl. ix–xiv; R. Zeiller, Notes sur les plantes fossiles de la Ternera (Chili), Bull. soc. géol. de Fr., 1874–1875, 3e sér., III, pp. 572–574, pl. xvii.

[2] H. Burmeister and C. Giebel, Die Versteinerungen von Juntas im Thale des Rio Copiapó, from the Abhandl. Naturf. Ges. Halle, 1861, VI, 4to, 34 pp., 2 plates.

[3] A. Pissis, Descripcion topográfica i jeolójica de la provincia de Aconcagua; Anal. Univ. Chile, 1858, pp. 46–89.

Ramada just mentioned, and south of it, at the bridge of the Incas in the pass of the Cumbre. At both places the underlying rock apparently consists, proceeding to the east, first of great masses of porphyry, then of granite. At the first locality Stelzner collected those fossils which enabled Gottsche to identify a whole series of horizons with those of the Jurassic system as it exists in Europe. At the second place he came to the conclusion that the eruptive rocks visible within the Jurassic system must be regarded as intrusive sills of trachyte, and not, as was formerly believed, interbedded porphyry flows. It would thus be a case of intrusion along the bedding planes, such as has been described in the north, by Moesta, in the silver mines of Chanarcillo[1].

This conclusion is not supported by the results subsequently obtained by Steinmann in the Cordilleras of Coquimbo and Copiapó. According to Steinmann, a very much altered limestone, containing a species of Avicula, rests directly on ancient crystalline rocks. Then follows, alternating with a system of porphyry and porphyry sandstone, a series of conglomerate, sandstone, and shale, with a flora of Rhaetic character; then Gryphaea limestone of the Lias, containing Arietites, *Gryphaea arcuata*, &c.; upon this the upper Lias; then several stages of the inferior Oolite of Europe, especially the zones of *Harpoceras Murchisonae*, *H. Sowerbyi*, and *Stephanoceras Sauzei*. Upon this last zone lies a great system, thousands of feet in thickness, of porphyry sediments and porphyry, which range up to the Cretaceous in age. Near Chanarcillo middle Neocomian and Urgonian are represented by limestones, also of European type; they thin out as they become intercalated with porphyry sediments[2].

It would thus seem that the beds of variegated sandstone with porphyry, which Brackebusch observed on the summit of the Silurian chains of Jujuy and assigned to the petroleum-bearing zone, should be regarded as belonging to the Mesozoic series of the great Cordillera.

The Jurassic system now extends towards the south; it is known to occur beneath the volcano San José, also beneath that of Tinguiririca, and indeed on both sides of the pass 'de las Damas.' According to an observation by Domeyko the granite is visible at the bottom of the valley of the Tinguiririca, on the west side of the Cordillera[3].

Throughout the province of Colchagua, and thus down to 35° 21′, the Mesozoic strata, according to Pissis, are confined on the west to the highest summits of the Andes; they attain their greatest development on the east

[1] A. Stelzner, Neues Jahrb. f. Min., &c., 1872, pp. 193–198, 630–636, and 1873, pp. 726–744; Gottsche, Ueber jurassische Versteinerungen aus der argentinischen Cordillera, Paläontogr., 1878, Suppl. III, 51 pp., 8 plates.

[2] G. Steinmann, Reisenotizen aus Chile; Neues Jahrb. f. Min., 1884, pp. 199–203.

[3] J. Domeyko, Excursion geológica á las Cordilleras de S. Fernando; Anal. Univ. Chile, 1862, pp. 22–42.

side[1]. In accordance with this Strobel found Jurassic fossils in greenish sandstone in the upper valley 'de las Leñas amarillas,' nearly two days' journey to the east of the watershed on Argentine territory. There, to the east of the Andes, granite crops out, and trachyte attains an extensive development. Trachytic detritus forms the surface of a great part, if not the whole of the Gran Pampas del Sur, south-west of San Rafael[2].

Traces of Mesozoic fossils have been found on the western slope of the Andes much further to the south; they are said to occur even in Chiloë. Steinmann records *Trigonia transitoria*, probably of lower Cretaceous age, from Caracoles in Bolivia, from the Cordillera of Chillan (lat. 36° 18′ S.), and even from the neighbourhood of the volcano Antuco (lat. 37° 16′ S.). The other accounts from these regions which are available to me are extremely scanty, and probably relate exclusively to Cretaceous outcrops, of which we shall soon have to record others in the south.—

As a general result it appears that the principal chain of the Cordilleras, in its course from the south of Peru through Bolivia and Chili, is built up of sediments, which, save for some Archaean exposed in the south, are certainly not older than the Permian, probably not older than the Rhaetic period. These sediments present, stage after stage, with a regularity absolutely astonishing, the character of the Jurassic and Cretaceous horizons of Europe. In the north they are chiefly developed on the west side of the great range. To the south they are known on many passes between the volcanos, and are found at great heights around Aconcagua, but south of the volcano Planchon they appear to pass more and more to the eastern slope. It would almost seem as though the universal deflexion of the Andes to the south-east were about to find expression in the course of this zone.

The zone supports extensive masses of volcanic lavas and ashes of recent date. Great independent mountains of trachyte rise from these or stand beside them, or in the intervals between their several parts. The active volcanos are situated, as we have said before, upon two distinct lines. The northern series, from Bolivia down to lat. 26° S., is entirely superposed upon the Mesozoic zone. The southern begins in lat. 34° in the same zone, but while the Jurassic beds appear to swerve towards the south-east, the volcanic line continues its course to the south.

*The Coast Cordilleras and Patagonia.* The principal chain of the Andes in Bolivia and Chili presents itself as the Jurassic zone of an extensive system of more or less parallel chains; but when we pass to the longitudinal depression which follows it on the west we are met with

[1] A. Pissis, Descripcion topográfica i jeolójica de la provincia de Colchagua; op. cit., 1860, pp. 659–715.

[2] P. Strobel, Beiträge zur Kenntniss der geognostischen Beschaffenheit der Anden vom 33° bis zum 35° s. Br.; Neues Jahrb. f. Min., 1875, pp. 56–62.

difficulties arising from the scarcity and not altogether concordant character of existing accounts, so that it is not easy to obtain a clear idea of the nature of this feature.

According to Pissis the beds underlying the desert of Atacama consist (apart from the above-mentioned deposits of red sandstone and Mesozoic limestone, which extend as far as the west side) of eruptive rocks of different age, so arranged that the oldest rocks appear on the west, and successively younger ones towards the east. In the west of the desert, near the Cordillera of the coast, and forming part of it, ranges of syenite are quoted by Pissis. These become rarer in the direction of the great depression, and are replaced by augite porphyry and amygdaloids, which in their turn give way to trachyte towards the east. Still further to the east, on the summit of the Andes, recent trachyte, lavas, and pumice occur [1].

In the south nothing similar has been observed. Pissis states that in the northern continuation of the longitudinal valley of Chili and in some of the southern parts of the valley itself, as in the provinces of Santiago and Colchagua, the red, probably Mesozoic, sandstone forms the greater part of the western declivity of the Andes and a good deal of the sides of the valley. In many places the slope of the Andes is covered by the lavas and ashes of the volcanos. Near Teno in the province of Colchagua a great lava stream from the Andes crosses the longitudinal valley and divides it in two. A considerable part of the depression is filled with an unstratified sheet of sandy clay, which contains *Mastodon Andium*, and presents, according to Domeyko, great resemblance to the clay of the Brazilian Pampas [2].

The structure of the *Coast Cordilleras* is typical of that of the great Pacific chains in general. We have already observed that in the north these chains are only represented by fragments, but that they become continuous as they proceed to the south. The rocks of which they are composed are very much disturbed in position, often intensely folded, and always present an ancient appearance. Eminent Chilian geologists see in them the representatives of the richly fossiliferous Silurian and Devonian formations of the high mountains of Bolivia. But in the whole region of these chains no determinable trace of organic remains of Palaeo-

[1] Pissis, Atacama; Anal. Univ. Chil., 1877, p. 576. We may probably regard the syenite as part of the Coast Cordilleras, the porphyry as Jurassic intercalation, the trachyte as the forerunner and foundation of the active volcanos.

[2] I. Domeyko, Algunas palabras sobre el terreno en que se hallan huesos de Mastodonte en Chile; Anal. Univ. Chil., 1868, pp. 369–374. Branco also describes *Mastodon Andium* from far in the north, in the high table-lands of north Ecuador, which, as we shall see directly, occur on a line in many respects homologous to that of the longitudinal valley of Chili: W. Branco, Fossile Säugethierfauna von Punin bei Riobamba, in Dames und Kayser, Paläont. Abh., 1883, I, p. 134. It is a species which is widely distributed, and Branco places the deposits of Punin on the horizon of the lower Pampas fauna.

zoic age has as yet been found *in situ*, and this supposition cannot therefore be considered as established by evidence.

D'Orbigny, it is true, states that he found in the north, in the Morro de Arica, fragments of Productus in blocks of limestone enclosed in porphyry, but D. Forbes, who subsequently described the Morro, did not consider that there was sufficient proof of its Carboniferous age. He met there with an alternation of curious porphyry and altered shales, as well as a thin layer of limestone with very doubtful organic remains, but did not venture to form any opinion as to their age[1].

Further to the south gneiss and granite also appear, as well as mica-schists and quartzites. This is already the case in Atacama, but the black cliffs near Cobija consist of a dark hard rock with disseminated epidote, which D. Forbes is inclined to regard as an argillaceous sedimentary rock, perhaps containing lime, altered by the proximity of the diorite or porphyry.

Near Mejillones granite occurs, and more to the south it frequently reappears on the coast. To the north of Valparaiso we meet with gneiss on the coast; above it lies quartzite, sometimes accompanied by talc schists, and there then follows, as the highest and most extensive member of this highly folded and dislocated complex, a series of slates, jasper-bearing beds, and quartzite.

Still further to the south, on the northern tributaries of the Rio Rapel; the Coast Cordillera breaks up into a series of low but rugged hills; soon, however, a fresh chain with more rounded summits comes in close to the coast. The mountains thus proceed to the south, cross the straits of Ancud, and form the series of islands which lie in front of the bay of Corcovado.

Isolated patches of a marine Tertiary formation already occur far to the north, where they are found on the slopes facing the sea, but these only attain a certain amount of continuity in the south, where occasional exposures of the upper or middle Cretaceous appear among them. These patches of Cretaceous and Tertiary rest directly on the gneiss, quartzite, or schists of the Coast Cordilleras, and the coal mines which are worked in them reveal the presence of numerous faults.

The most important outcrops of this kind are the green sandstone with abundant Baculites of upper Cretaceous age, found at Tomé in the bay of Talcahuano and the coal-bearing Tertiary beds of the bay of Arauca; these form the twofold indentation of the coast; they have already been mentioned above (p. 99, Fig. 6). To the north and south of this region more recent strata are repeatedly met with. Concha y Toro assigns approximately to the middle Eocene period the Tertiary beds which rest against the Coast Cordillera and descend towards the sea in the province of Santiago, and

[1] D. Forbes, Bolivia and South Peru; Quart. Journ. Geol. Soc. 1861, XVII, pp. 35, 36.

particularly those which occur between Rio Maipo and the promontory of Topocalma [1].

The Cordillera of Nahuelbuta runs through Arauco as a part of the Coast Cordilleras. According to Philippi it increases towards the south both in height and breadth, attains an altitude of 1,500 meters, and is formed of granite and mica-schist. On the west it is bordered by a plateau about 150 meters high, which consists of the coal-bearing Tertiary deposits [2].

In the bays of Talcahuano and Arauco we perceive clearly that the patches of recent sediments follow the same direction as the Cordillera and the coast; we also know from Darwin that a number of small outlying islands consist of marine Tertiary beds: as instances of such islands we may cite Mocha (38° 20′), Huafu south-west of Chiloë, Ypun (44° 36′), and, according to Simpson's observation, probably also Huamblin (Socorro), situated to the south-west of Ypun, as well as Lemu (45° 12′). It would therefore appear that extensive bands of Tertiary are present which follow the direction of the coast.

Our knowledge of the extreme south-western and southern parts of America rests chiefly on the observations made by Darwin now nearly seventy years ago, and on the important investigations of Steinmann, unfortunately only as yet made known in abstract. The general features of the structure, so far as I can gather, appear to be as follows [3]:—

From Valdivia a zone of mica-schist proceeds which forms the whole of the west and south of Chiloë, while the middle of the island is said to consist of granite and greenstone: in the north volcanic formations appear, and the east is almost entirely covered with beds of boulders and pebbles.

In the Chonos islands we again see mica-schist and clay-slate, as well as some ancient eruptive rocks. On the mainland Simpson, who penetrated up the lower course of the Rio Aysen to about lat. 45° 20′ S., received the impression that the mountains to the south, and probably also to the north of this river, no longer formed a continuous cordillera, but consisted of isolated mountains only united by the formation of recent alluvial land. To the north of Aysen, at the foot of Monte Macá, the same observer marks a little inactive volcano [4].

[1] Concha y Toro, Carbon fósil, Anal. Univ. Chil., p. 358; also Mallard et Fuchs, Notes sur quelques points de la géologie du Chili, Ann. des Mines, 1873, 7e sér., III, p. 91 et seq.

[2] Philippi, Bemerkungen über die chilenische Provinz Arauco, Petermann's geogr. Mitth., 1883, pp. 453–460; also J. P. Sieveking, Geognostische Skizzen aus der chilenischen Provinz Arauco, op. cit., pp. 57–61; the same granite range also in Pissis, Chaîne des Andes, Ann. d. Mines, 1873, p. 413.

[3] Darwin, Geological Observations, p. 435 et seq.; Steinmann, Reisenotizen aus Patagonien, Neues Jahrb. f. Min., 1883, I, pp. 255–258.

[4] E. Simpson, Reconocimiento del rio Aysen, Anal. Univ. Chil., 1870, p. 128; map of this region in Petermann's geogr. Mitth., 1878, pl. 24, and 1880, pl. 8.

Rocks similar to those of the Chonos islands also form, according to Darwin, the promontory of Tres Cerros (46° 50′); the mica-schists are accompanied by lustrous schists and a somewhat anthracitic schist: a great deal of quartz is present. The mean strike is N. 19° W.

A broad zone of sedimentary rock, which Darwin refers to as 'clay-slate,' is said by Steinmann to be distinguished from the rocks generally known under this name by numerous intercalations of hard sandstone. It commences as far north as Valdivia, according to Steinmann, and extends along the east side of the mountains. This zone reaches the waters of the straits of Magellan in the peninsula of Brunswick, forms on the south-east both sides of Admiralty Sound, then reaches the Beagle channel nearly east of its point of bifurcation, forms both its shores as far as the straits of Le Maire, and, south of the Beagle channel, the entire island of Navarin, and the eastern half of the island of Hoste and the peninsula of Hardy. Against the northern border of this great zone there rest in Tierra del Fuego horizontal beds of Tertiary and even more recent age: these form the whole table-like land as far as St. Polycarp's bay.

The whole of this great mountain zone is of Cretaceous age. Even far in the north, between the Laguna Argentina and Laguna Rica, Steinmann observed two horizons distinguished by different species of Inoceramus; further south, at the foot of the Cerro Painé (about 51° 30′), he found Haploceras, Ananchytes, and other upper Cretaceous fossils; finally, two degrees more to the south, on the Rio San Juan in the peninsula of Brunswick, he again found specimens of Inoceramus. On Mont Tarn and at Port Famine dark calcareous beds are present; here lower Cretaceous fossils were found, first by Hombron and Grange, and then by Darwin: *Ancyloceras simplex*, d'Orb., occurs here. Finally in the south-east part of this zone, in Nassau bay, Dana came across great numbers of that singular fossil, belonging to the Belemnitidae, which he called *Helicerus fuegensis*[1].

This Cretaceous zone assumes in places a Palaeozoic appearance. The slates are traversed by dykes, frequently even by great masses of an ancient eruptive rock containing a good deal of hornblende. Old eruptive rocks of this kind play a considerable part in the formation of the Wollaston, Hermite, and Hoorn islands. The outlying islands, Ildefonso and Ramirez, seem, from specimens collected by Wedell, to consist of an ancient porphyritic lava. More recent volcanic material is entirely absent in Tierra del Fuego.

To the west of the bifurcation of the Beagle channel, says Darwin, the ancient volcanic rocks disappear, and we see the clay-slate passing into a zone of lustrous schists and fine-grained gneiss, which is followed by a great band of garnet-bearing mica-schist. The western part of this region appears to be formed solely of gneiss and hornblende-schist, which

[1] Dana, in Wilkes, Exploring Expedition, Geology, pp. 601-606, 720.

rest on barren granite mountains, and it is probably these rocks which are continued to the north through Desolation Land. The most westerly series of islands on its coast consist again of ancient eruptive rocks [1].—

We observe that the American mountains bend right round in the south, first to the south-south-east, then to the south-east, to the east, and finally even, according to Darwin, to east-north-east.

Further, these southern mountains are not to be regarded, as we are generally inclined to assume, as a continuation of the principal chain of the Cordilleras; they correspond to the Coast Cordillera. Judging from descriptions, the Morro de Arica, far in the north on the coast of Bolivia, and perhaps the cliffs of Cobija, are those which, among all the features hitherto mentioned, present the greatest resemblance to the mountains of Tierra del Fuego.

Darwin was somewhat inclined to regard the bands of gneiss and mica-schist as altered Cretaceous rocks; Steinmann has up to the present treated this important question with great hesitation and reserve [2].

It has been shown that the eastern sierras of the Argentine Republic, formed of very ancient rocks, are bent out of the meridional direction and are continued to the south-east in Sierra Tandil and Sierra Ventana. There are some indications which suggest that the Jurassic zone is similarly deflected, and now we have before us a long mountain range, which must be regarded as the continuation of the Coast Cordilleras, likewise bent round in the same direction. The recent volcanos do not follow this deflexion. We might perhaps hope to gain further light from a study of the Falkland islands; these, however, are of a completely different character, and consist of folded strata, with Palaeozoic fossils [3].

*Peru.* The high mountains of Potosí and Cochabamba slope down on the east to the broad plain, covered by the primeval forest of Santa Cruz de la Sierra. Two great rivers rise on the slope not far from one another: the Rio Grande, which flows north to the Amazon, and the Pilcomayo, which flows south to the La Plata. The watershed between the two is, however, so feebly marked that the Rio Parapiti, which rises here, loses itself in the swamps of the virgin forest, and only finds an outflow during floods.

Far and wide the forest-covered plain surrounds the eastern foot of the high mountains, till near the boundary of Matto Grosso a long low chain emerges from it running parallel to the Andes; the south-eastern extremity of this reaches the alluvial land of the Paraguay. It consists, as d'Orbigny

[1] B. Bossi, Exploracion de la Tierra del Fuego con el vapor oriental Charrúa, 8vo, Montevideo, 1882, pp. 17, 27, 37, only states in general terms that the whole outer chain from Desolation to Wollaston and Staten island consists of granite, gneiss, and quartzite, and forms the continuation of the Andes.

[2] Darwin, op. cit., p. 446; Steinmann, p. 256.

[3] Darwin, On the Geology of the Falkland Isles; Quart. Journ. Geol. Soc., 1846, II, pp. 267-274.

has shown, of gneiss, ancient schist, and quartzite [1]. It seems to stand in the same relation to the Andes as the Argentine Sierra de Córdoba.

Let us now turn to the high mountains of the west.—

We began our description of the main range of the Cordilleras with the Andes of Bolivia, not because any particular change of structure makes its appearance in this region, but on account of the more exact knowledge we possess of it. We cannot, however, deny that towards the north a gradual change of relations very slowly sets in.

In the south we have seen the parallel chains of the Argentine Republic rise towards the interior of the continent; they are composed of Archaean and Palaeozoic rocks, and are followed towards the sea by the Jurassic zone on which volcanos are set: on the shore rising in front of this are the ridges and cliffs of the Coast Cordillera, in which no fossiliferous strata are known of greater age than the Cretaceous.

Further to the north, the Bolivian Andes present a very similar structure notwithstanding a slight deflexion of the strike to the north-west. The Silurian Sierras of Salta and Jujuy find their prolongation in the lofty mountains of Illampu and Illimani; in front of them lies first a zone of Devonian, and then of Carboniferous limestone which runs from Cochabamba through lake Titicaca towards Carabaja and Cuzco. This is followed towards the sea by porphyry and red sandstone, then by the Mesozoic zone with its volcanos, and finally by the reefs of the Coast Cordillera near Arica and at other places.

The districts of Ayacucho and Huancavelica and the neighbourhood of Lima already show, according to Crosnier's description, some change of structure [2].

We may start from the strand near Ica, and ascend to the argentiferous region of Castro Vireina, on the west slope of the western Cordillera, or, again, we may start from Lima and proceed up the valley of the Rimac; but in either case we shall first come upon the broad, often gold-producing granite ridges of the Coast Cordillera, and these are accompanied by upturned beds of limestone and sandstone, which appear to belong to the lower Cretaceous. The same strata form the little promontory of Chorillos and the island of San Lorenzo near Lima [3].

[1] A. d'Orbigny, Voyage dans l'Amérique méridionale, 4to, 1842, III, 3, Géologie, p. 181 et seq.

[2] L. Crosnier, Notice géologique sur les départements de Huancavelica et d'Ayacucho, Ann. d. Mines, 1852, 5e sér., II, pp. 1–113, pl. i; also Pflücker y Rio, Ueber den Minendistrict Yauli in Peru; Kerl u. Wimmer, Berg- u. Hüttenm.-Zeitung, 1884, XLVIII, p. 341 et seq.

[3] Gabb has described an *Ammonites Raimondianus* from Raimondi's collections at the Cerro del Salto del Frayle near Chorillo. He compares it with the *Amm. cymodoce*, d'Orb., from the upper Jurassic. Professor Neumayr agrees with me that the form represented is most closely allied to the Hoplites of the Neocomian. The rock is said to correspond

After crossing the granite, we shall find above Lima stratified rocks, resembling porphyry, similar to those which play so important a part in Chili, and these are followed by abrupt walls of steeply upturned Mesozoic limestone, which extend as far as the head of the pass, over 4,800 meters high. This mass of limestone forms for a great distance the ridge of the western Cordillera, as it does also in north Chili. On the eastern declivity the limestone is again followed by another band of the so-called stratified porphyry, then by a great mass of stratified coal-bearing sandstone and quartzite, in which the longitudinal valley of the Oroya has been eroded.

The observations of Crosnier permit us to continue this transverse section over a more southerly part of the longitudinal valley, namely from Ischuchaca across the Pampas towards Cochabamba, at the east foot of the eastern Cordillera. Beneath the carbonaceous sandstone dark limestone and porphyry conglomerate crop out; then follows, with complete change in the forms of the mountains, a band of clay slate and green chloritic schist, until near Cochabamba a long ridge of granite appears.

We will now make a short digression to consider the carbonaceous sandstone which runs between the first and second Cordillera. It is this sandstone which carries the rich silver mines of Huancavelica, situated on the east side of the western Cordillera.

In the quicksilver mine of Ventanilla, south of Huancavelica itself, Crosnier observed a bed of coal. The cinnabar has penetrated into the interstices and fissures of the sandstone. The sandstone and the shales which frequently accompany the coal contain Ammonites. In this region, in the longitudinal valley of the Oroya and Jauja, the beds frequently afford fossils, as for example near Tingo and in the Quebrada of Huari. The coal-bearing beds of Pariatambo and of Cerro della Ventanilla also occur here, but there is a difference of opinion as to their age. Gabb places them in the Lias; Steinmann, probably with greater reason, in the Cretaceous [1].

This coal and quicksilver bearing horizon is already known in Bolivia, near Puno, that is on the inner side of the great Mesozoic zone towards lake Titicaca, and here too it appears on the east side of the

to that of the island of San Lorenzo. From the hill near the Hacienda del Imperial, near Canete, also in the coast zone, Gabb further describes *Cardita exotica*, d'Orb., a form described by d'Orbigny from imperfect specimens found in the Cretaceous of Columbia: Gabb, Description of a Collection of Fossils made by Dr. A. Raimondi in Peru, Journ. Acad. Nat. Sc., Philadelphia, 1877, new ser., VIII, p. 268, pl. 37, fig. 2, and p. 287, pl. 41, figs. 1, 2. The locality of the beds mentioned here, Tingo in Huari, must not be confounded with the Lias beds of Tingo, west of Chachapoyas, which lies much further north; cf. Habenicht's map in Petermann's geogr. Mitth., 1879, pl. iii.

[1] G. Steinmann, Ueber Tithon und Kreide in den peruanischen Anden, Neues Jahrb. f. Min., 1881, II, pp. 130–153, pl. vi–viii; and Ueber Jura und Kreide in den Anden, op. cit., 1882, I, pp. 166–170.

limestone zone which forms the greater part of the western Cordillera. From Huancavelica it extends for many miles along the eastern slope of the western chain, and Peruvian miners even assert that it is prolonged without interruption, but with variable richness, through the whole of north Peru.—

For the ranges to the north of Lima the works of Raimondi are a mine of information, in particular his comprehensive description of the department of Ancachs[1]. There now appear, to the east of a low chain which borders the coast, three great Cordilleras and three longitudinal valleys. The first Cordillera we will call, with Raimondi, the *Cordillera Negra*; it slopes eastwards down to the first great longitudinal valley, the Callejon de Huaylas. The Callejon is bent on the north towards the sea in a great bow, the front of which lies in about lat. 8° 40′ S.; it cuts through the Cordillera Negra; the river which flows through it, known in this region as the Rio de Santo, reaches the sea in lat. 9° S.—The second chain is the *Cordillera Nevada*; it is united with the Cordillera Negra in the south, and runs parallel with that chain to the north-north-west; it slopes westwards to the Callejon de Huaylas, eastwards to the Marañon, and thus forms the watershed between the two oceans.—To the east of the Marañon, between this river and the Huallaga, lies the third chain; we will term it the *eastern Cordillera*; we possess only the most meagre information regarding it.

If now, making use of Raimondi's data, we trace the structure of this country from the sea towards the interior, we shall find first that the zone which runs in the immediate neighbourhood of the strand is formed of low hills of syenite, or granite, or of a greenstone which is frequently covered by a red layer due to weathering. Along with these ancient-looking rocks there appear in several places, just as in the south, patches of unfossiliferous sandstone and shale, as for instance in the harbour of Casma and on the Culebra, and in the latter place these strata are bent into such striking serpentine folds that Raimondi thinks it possible the name 'Culebra' may have been suggested by this circumstance.

This range, which in the whole region of Ancachs rises from the sand of the coast district, sometimes in isolated hills, sometimes, as between Casma and Nepeña, in continuous ridges, forms without doubt the continuation of the Coast Cordilleras of the south.

The Cordillera Negra consists almost exclusively of Mesozoic strata, having a general inclination towards the sea; they are composed almost exclusively of sandstone and shales; limestone is visible only in very small quantity, and no continuation of the limestone range which

[1] A. Raimondi, El departimiento de Ancachs y sus riquezas minerales, published by Enr. Meiggs, large 8vo, Lima, 1873, in particular pp. 267–301.

rises above Lima is to be found here. These beds of limestone and shale contain coal. They correspond no doubt to a large extent with the coal-bearing deposits of Pariatambo.

The Cordillera Negra is traversed in many places by a recent diorite, which constantly accompanies the silver ores of this range.

The Callejon owes its existence chiefly to erosion. The western flank of the Cordillera Nevada is formed of beds of coarse white or bluish sandstone, which although steeply upturned dip in the same direction as the series of the Cordillera Negra; the whole mass of the latter therefore overlies the beds of the Cordillera Nevada.

Towards Huaraz and Caraz the sandstone beds of the western Cordillera Nevada are accompanied by marl and limestone which form subordinate chains.

The highest summits of this mighty chain consist of superimposed masses of trachyte. Granitic rocks are certainly mentioned, but Raimondi repeatedly emphasizes the fact that they are difficult to distinguish from trachytes and that they are of recent age.

The greenstones of the Cordillera Negra hardly attain so great a height as the summits of the Cordillera Nevada; on the other hand, isolated masses of trachyte, particularly trachytic conglomerate, appear in horizontal beds even on the summits of the Cordillera Negra; Raimondi thinks it probable that these are derived from eruptive centres on the Cordillera Nevada and date from a period when the Callejon, the erosion valley which at present separates the chains, did not yet exist.

No active volcanos are known either on the Cordillera Negra or on the Cordillera Nevada.

On the east side of the Cordillera Nevada, beyond the trachyte summits, we find in the provinces of Huari and Pomabamba steeply upturned, probably also folded beds of altered sandstone extending up to the snow-line.

In the south of Huari, however, and a large part of Pomabamba this sandstone is overlaid by more recent, but similarly disturbed beds of shale and sandstone with coal; these are no doubt a recurrence of the coal-bearing deposits of the Cordillera Negra.

Whether the coal-bearing horizon belongs to the Jurassic system or to the Cretaceous, there is no doubt as to the existence above it of a recent Cretaceous marl lying unconformably, in which many Echinoids, as well as Actaeonella, Ostrea, *Neithea quinquecostata*, and species of Buchiceras, occur. It is found on both slopes of the Cordillera Nevada, on the one hand in the district of Cajatambo, on the other as far as the Marañon.

On the south side of this slope, near the head-waters of the Marañon, lies the place called Huallanca, from which Steinmann has described *Perisphinctes senex* of the Tithonian, as well as *Brancoceras aegoceratoides* and *Acanthoceras Lyelli* from the horizon of the Albian or Gault.—

The course of the Marañon does not correspond altogether to the strike of the strata. In one part of its upper course its bed is excavated in ancient gold-bearing talc schist, which, accompanied by granite from the lofty eastern Cordillera, crosses over near Uca, somewhat south of lat. 9° S., to the left bank of the river. Further to the north, near Puerto di Puruay, the river has sunk its bed in thick beds of red sandstone and marl with gypsum and salt; they are bent into an anticlinal, and are regarded as Trias; above them lies limestone presumably of Jurassic age and then the Cretaceous marl. The red sandstones probably form the basement of the whole stratified series of the Cordillera Nevada and the Cordillera Negra.

The slope of the eastern Cordillera, which is situated on the other side of the Marañon, consists of gold-bearing talc schist of Palaeozoic or even greater age. In the neighbourhood of the town of Pallasca, near the boundary of Ancachs and Libertad, this ancient auriferous schist crops out in a single locality, from amidst the Mesozoic deposits of the northern Cordillera Nevada.—

In this part of Peru the structure of the mountains is thus somewhat as follows:—

The general trend of the beds and the chains, of the sea-coast and the great river valleys, is directed to the north-north-west.

On the coast, rocks occur having a very ancient appearance; they are followed by shales and sandstone, which resemble those of the Coast Cordilleras of Bolivia and Chili.

The Cordillera Negra and Cordillera Nevada, that is, all the mountains which extend as far as the Marañon, consist of Mesozoic strata, which probably belong for the most part to the Cretaceous system. The summits of the Cordillera Nevada and some of the summits of the Cordillera Negra are crowned by trachyte.

At one locality on the Marañon red sandstone with salt and gypsum crops out from beneath the strata of the Cordillera Nevada.

To the east of the Marañon lie the great masses of ancient schist and granite, so that the high mountains which, from the Illimani and Illampu, form the Cordillera of Carabaya and the chains of Cuzco, can only find their continuation between the Marañon and the Huallaga.

In conclusion I will mention that Raimondi records traces of comparatively recent volcanic rocks at two places in the immediate neighbourhood of the coast, namely, basalt near the Culebras and a lava south of Casma. This is the more noteworthy, since in the adjacent parts of the sea many indications of volcanic activity are known, and quite recently, in the year 1881, not very far from this place, a new volcanic island is said to have formed in lat. 7° 48′ S., long. 83° 48′ W., 188 knots from Punta Aguja [1].

[1] Note in Nature, Oct. 3, 1881.

The descriptions given by Orton of the geological structure of the most northerly part of Peru, and his section from Pacasmájo to the Huallaga, do not appear to me to be sufficient to enable us to determine the main features of the structure of this region with any degree of certainty[1]. They probably repeat in a general way those of Ancachs. The occurrence of the genus Buchiceras, observed by Hyatt at Cachiyacu west of the Huallaga, then at Cayamarca, and north of it near Celendin, indicates a continuation of the Cretaceous beds beyond the valley of the Amazons[2]. Orton and Hyatt cite Lias fossils from Ipishguanüna (Piscoguanuna) between the Marañon and the Huallaga, and from Tingo near Chachapoyas.

*Ecuador, Columbia, and Venezuela.* During the last few years the structure of the south of Ecuador has been made known in greater detail by the admirable investigations of T. Wolf[3].

From the southern boundary of this state to about lat. 2° S. the Andes consist of two parallel Cordilleras which are frequently united in the south. The eastern Cordillera is composed of gneiss, mica-schist, chloritic schist, and other ancient crystalline rocks; these strike, like the Cordillera itself, from south to north; their extension towards the east is not known. The western Cordillera, on the other hand, is formed of ancient eruptive rocks of great variety, which are described as 'porphyries and greenstones'; some granite masses also crop out among them. Towards the north conglomerates and rocks resembling Flysch appear as an additional member.

On the west side of the western Cordillera, Cretaceous deposits appear in the direction of the sea; the gulf of Guayaquil restricts the region they occupy, but to the north of it they reappear with an imposing breadth and extend thence far to the north. Eruptive greenstones accompany the Cretaceous, especially in the provinces of Guayaquil and Manabé[4].

The boundary region between the eastern and western Cordillera runs between the meridians of 79° and 80°, and is termed by Wolf the *intra-andean region.* It is of the greatest tectonic importance. Within it, south of the town of Loja and also near the town itself, lie two depressions filled with recent leaf-bearing beds. Somewhat further to the north, near the head-waters of the Rio Jubones, there appear in this intra-andean region,

[1] J. Orton, The Andes and the Amazon, 8vo, 3rd ed., 1876, in particular p. 551 et seq.

[2] A. Hyatt, The Jurassic and Cretaceous Ammonites collected in South America by Prof. J. Orton, with an App., &c.; Proc. Boston Soc. Nat. Hist., 1874–1875, XVII, pp. 365–372.

[3] T. Wolf, Viajes científicos por la Republica del Ecuador, 3 Hefte (Loja, Azuay, Esmeraldas), 8vo, Guayaquil, 1879; and Zeitschr. deutsch. geol. Ges., 1876, XXVIII, pp. 391–393, map.

[4] T. Wolf, Geognostische Skizze der Provinz Guayaquil; Neues Jahrb. f. Min., 1874, pp. 385–396.

succeeding each other along a line running from south, somewhat west, to north, somewhat east, the first forerunners of the great volcanos of northern Ecuador. These are formed chiefly of andesite. They appear in three regions: on the upper Jubones, then south of Cuença, and, lastly, north of this town in Azuay.

Between the two last-named volcanic masses there appears, north-east of Cuença in the intra-andean region, a curious mass, the 'Arenisca de Azogues,' which consists of sandstone with quicksilver. It is bluish grey in colour, weathers spheroidally, is bleached by the alteration of the iron, and is accompanied by shales. The stratification is very much disturbed; the strike corresponds to that of the intra-andean region. The remains of old workings for quicksilver are found in it and it affords asphalt and other bituminous materials. From this description the idea is at once suggested that this is a continuation of the great quicksilver zone of Peru.

Crossing southern Ecuador from east to west we thus meet, in the east, with gneiss and ancient crystalline rocks; then in the intra-andean region leaf-bearing deposits, the first masses of andesite and the patch of sandstone with quicksilver and asphalt, and, in the west, various porphyries and greenstones which are succeeded towards the sea by the Cretaceous formation.—

The continuation of these chains towards the north may be traced by the observations given in the works of Reiss [1].

The eastern Cordillera in this region also consists of gneiss and other ancient rocks, which, in the case of a few summits, reach a height of 4,500 meters, and on the Saraurcu in the north even of 4,800 meters. The intra-andean region of the south is here represented by the high plateaux of Riombamba, Latacunga, and Quito covered with lavas, tuff, and ash. The western Cordillera is formed of soft, chiefly black, shales traversed by various greenstones, and of massive beds of sandstone. Towards the west it descends steeply to the sea. Shales and sandstone extend, according to Reiss, far to the north and the south, and are correlated, like the equivalents of the same rocks in Columbia, with the Cretaceous. They recall in many respects the Flysch of Europe. In this western Cordillera we recognize the continuation of the Coast Cordilleras of the south.

Volcanos stand as 'completely independent structures' on the monotonous crest of these Cordilleras, as well on the eastern as on the western range. On the former there rise Altar, Tunguragua, Cotopaxi, Antisana, and

[1] W. Reiss, Bericht über eine Reise nach dem Quilotoa und dem Cerro Hermoso in den ecuadorischen Cordilleren, Zeitschr. deutsch. geol. Ges., 1875, XXVII, pp. 274–294; by the same, Die geol. Verhältnisse der Fundstellen fossiler Säugethierknochen in Ecuador (in Branco, Säugeth.-Fauna von Punin bei Riobamba), Dames u. Kayser, Paläont. Abh., 1883, I, pp. 41–56, map, et passim.

others. On the western Cordillera they are still more numerous; here I need only mention Chimborazo, Quilota, Iliniza, Corazon, and Pinchincha.—

We now reach on the north that region in which the several branches of the Andes diverge from one another, and where in particular a mighty arc is detached east of the Magdalena river, which proceeding far to the north-east forms the Sierra de Bogota and the Sierra de Merida. These branches are not accompanied by active volcanos. Granite and gneiss are found in them. It is only quite recently that they have afforded some traces of Lias[1]. As a rule, however, the sedimentary series begins with the lower Cretaceous, which in this region also is represented by shales, thick beds of sandstone and dark bituminous limestone, occasionally accompanied by ancient eruptive rocks, as in the western Cordillera of Ecuador. The rich fauna of these deposits has been made known by L. v. Buch, d'Orbigny, Forbes, and in particular Karsten; according to Uhlig the beds are shown by a series of forms to correspond to the deposits of Barrême in the south of France, and of Wernsdorf in the Carpathians[2].

Karsten mentions, as a remarkable fact, 'that the steep slopes of this lower Cretaceous region, which trends almost in an arc to the north-east, are directed towards the mountains of Guayana, the rounded granitic summits of which, as far as these mountains are known, rise from the Tertiary plain like islands from the ocean.' These great chains thus appear to be unilateral in a direction turned away from the Brazilian mass, and the same character seems to obtain, according to Karsten's observations, in the Sierra Santa Marta, which follows to the north; at the south foot of this sierra copper-bearing eruptive rocks predominate, and in its continuation, near the lakes of Maracaibo, petroleum wells up out of the Cretaceous beds[3].

We may represent to ourselves the Brazilian mass as engirdled by the arc of the Sierra de Bogota and Sierra de Merida, and the rocks of this arc as dipping generally towards the exterior; but more to the north-east the relations are essentially different.—

From the observations of Karsten it already seemed probable, and the subsequent investigations of Sawkins, Wall, and Crosby have since established the fact, that the great mountain range, which runs from west to east and forms the north of Venezuela and the island of Trinidad, is composed of

[1] Steinmann, Ueber Jura und Kreide in den Anden; Neues Jahrb. f. Min., 1882, pt. 1, p. 169.

[2] H. Karsten, Ueber die geognostischen Verhältnisse des W. Columbien, der heutigen Republiken Neu-Granada und Equador, Amtl. Ber. üb. die 32. Versamml. deutsch. Naturf. u. Aerzte zu Wien, 1858, pp. 80–117, map; V. Uhlig, Die Cephalopoden-Fauna der Wernsdorfer Schichten, Denkschr. Akad. Wiss. Wien, 1883, XLVI, p. 158 et seq.

[3] A large number of facts certainly point to the greater independence of the Sierra S. Marta in accordance with the older view of Humboldt; so particularly Acosta, Bull. Soc. géol. de Fr., 1852, 2e sér., IX, p. 396, and in part also Cornette, tom. cit., p. 509 et seq.

rocks very similar to those of the sierras mentioned above, but arranged in inverse order. Its oldest rocks lie towards the north and form the steep coast of the Caribbean sea [1].

From Valencia to the north-eastern extremity of the island of Trinidad there runs a long range of schist mountains, frequently garnetiferous, in which gneiss and eclogite occur in places apparently as intercalations. This range is somewhat broader in the west and there attains a height of 8,000 feet; it surrounds lake Valencia and the neighbourhood of Caracas, is interrupted by the bay of Barcelona, and forms, on the other side of the bay, the promontory of Araya, which bounds the bay of Cariaco on the north; it then forms the peninsula of Paria, and finally the whole north coast of Trinidad. Here its height has decreased to about 3,800 feet.

On this zone of schist there rests in the west, south of lake Valencia, a great band of ancient eruptive rocks, which appear to be not less various than those of the western Cordillera of Ecuador; with these there appear on the north masses of rock resembling diallage and serpentine. There then follows to the south a long zone of quartzite, slate, and limestone of the lower Cretaceous. On both sides of the bay of Barcelona the lower Cretaceous may be seen in direct contact with the ancient zone of schists; it strikes through Cumana towards the east, but does not, however, quite reach the western side of the gulf of Paria. Beyond this gulf it again crops out, and traverses the island of Trinidad in two parallel ranges from west to east.

At several places within this zone the lower Cretaceous fossils of Bogota have been found, and Karsten distinguishes besides a more recent division with Hippurites. To the south of this lie marine strata of upper Tertiary age, which enter the country through the bay of Barcelona and dip beneath the llanos which slope down to the Orinoco.—

Thus the northern coast range from Valencia to Trinidad is not constructed on the same fundamental plan as the other ranges of South America, at least as far as we are able to judge of them. In this case we have a long unilateral range which, like so many European chains, turns its oldest rocks and most of its steep cliffs towards a sunken area, the Caribbean sea. The chain is not only broken off; in-breaking has also occurred, namely, in the bay of Barcelona. The gulf of Paria, which the Orinoco is silting up, is connected with the Caribbean sea by a strait, which, according to Guppy, has been caused by a fault with downthrow on the

[1] Karsten, Beiträge zur Kenntniss der Gesteine des N. Venezuela, Zeitschr. deutsch. geol. Ges., 1859, XI, pp. 345-361, map; G. P. Wall, On the Geology of a Part of Venezuela and of Trinidad, Quart. Journ. Geol. Soc., 1860, XVI, pp. 460-470, map; W. O. Crosby, Notes on the Physical Geography and Geology of Trinidad, Proc. Boston Soc. Nat. Hist., 1878, XX, pp. 44-55; further, the Reports Geol. Surv. West. Ind. of Sawkins and Wall.

east, but, according to Crosby, by the more southerly position of the mountains of Trinidad. The statement that Palaeozoic sediments also occur here requires confirmation. In structure and position this range resembles, above all, the north African chain between Gibraltar and cape Bon, the Mediterranean corresponding to the Caribbean sea.

The great earthquakes of Cumana and Caracas are propagated from the fractured border of this range. Towards the south it is separated from the Brazilian mass by the broad valley of the Orinoco, which here occupies a position similar to that of the lower Rhone or of the Guadalquivir.

*Summary.* South America presents in a higher degree than any other part of the world all the features of a homogeneous structure. In the east and in the centre lies the broad Brazilian platform with flat-lying Palaeozoic sediments characterized by a discontinuity in the succession of the marine deposits such as we have already encountered in several other table-lands.

If we approach the great mountains from the east we first meet with short chains, wholly or at least chiefly of Archaean age, as for instance the sierras west of Cordoba, and the mountain range in the east of the Bolivian Andes. The Palaeozoic chains, principally Silurian, form a continuous zone of much greater length. It has been traced from the south of Peru through Bolivia as far as Mendoza. The Jurassic deposits extend still further, both to the north and south; they include the principal chain of the Cordilleras, together with the greater part of the recent volcanos. Finally, on the west coast, where we should expect in Europe to find the Flysch-zone, there rises the alien series of the Coast Cordilleras, formed of rocks bearing an Archaean stamp, such as gneiss and mica-schists, of various old eruptive rocks, and finally of deposits of sandstone and shales generally devoid of fossils. They are represented along the whole coast, from Peru and Bolivia, from Casma and Nepena (lat. 9° 10′ to 9° 30′ S.) to the Culebra, from Ica to the Morro de Arica, and to Cobija and Mejillones, now by isolated summits, now by longer ranges. In Chili they form continuous chains which accompany the coast. Further to the south they compose the west coast of Patagonia and the islands bordering it, and even when the Andes have disappeared they continue far to the south, and describe a great curve from south to south-east, east and east-north-east through Tierra del Fuego towards Staten island.

The scanty traces of fossils found in Peru point to the Cretaceous formation: in the Patagonian mountains also only Cretaceous fossils are known.

The same structure is repeated in the north. The great sierras which run northwards from Ecuador and then diverge in virgation, especially

the great arc of the Sierra de Bogotá and Sierra de Merida, which runs to north-east, are formed almost exclusively of Archaean rocks and Cretaceous deposits.

The long coastal chain on the north of Venezuela and Trinidad consists of the same formations, but its tectonic importance can only be estimated in connexion with the West Indian islands.—

As we proceed to the west the zones of the great mountain system of South America become longer and the sediments more recent. Whether the rocks of Archaean character which appear in the Coast Cordilleras are really of Archaean age or not is a great unsolved problem. Darwin doubted it in the south: it is the same difficulty which presents itself in Greece, in the Taurus, on the Andaman and Nicobar islands, and will shortly confront us again in North America.—

In the north the chains diverge in virgation through New Granada and towards Venezuela, and this is also the case in the south from Cabo Corrientes as far as Staten island. The syntaxis in Arica is marked by a moderate curvature of the chains; its influence on the distribution of the sediments and the plan of the whole is but slight. This plan, in so far as we are dealing with the western part of South America, is more or less concentric. The contrast between the south European and the South American mountains results from the circumstance that in the Alps, Carpathians, and Apennines the backland has subsided, and in the Alps and Carpathians the foreland is still visible, while in South America the Brazilian mass occupies the place of the backland within the arc, and the foreland lies beneath the ocean.

The arrangement of the volcanos is also essentially different from that of the volcanos of the western Mediterranean, or of the extinct volcanos of the Carpathians. They do not rise from an inner fractured border, but from the very midst of the mountain summits, like Demavend, Elbruz, and Kasbek. In Ecuador they sometimes stand, like Chimborazo, on the western Cordillera, which we must regard as the continuation of the Coast Cordillera; sometimes, like Cotopaxi and Altar, on the eastern Archaean Cordillera; and to the south, down to the Rio Jubones, south of Cuença, they are situated on the boundary between these two Cordilleras in the intra-andean region. Still further south, through Bolivia and Chili, their great ash cones rest for the greater part on the Jurassic zone.

The volcanos do not follow the deflexion of the chains either towards Venezuela in the north, or towards Tierra del Fuego in the south. They continue to follow the Pacific coast.

Fernando Noronha, which rises to the east of the Brazilian mass from the depth of the Atlantic Ocean, consists of basalt and phonolite. The only considerable group of islands in the neighbourhood of the west coast, that of the *Galápagos*, is also volcanic, and its lavas are basaltic. Numerous craters

are present. T. Wolf rightly places these islands among the grouped volcanos as opposed to the serial volcanos of the mainland, and emphasizes the petrological contrast between them and the volcanos of Ecuador, which consist chiefly of trachytic and andesitic rocks[1].

The volcanic groups of Italy, such as the Lipari and Ponza islands, are on the other hand distinguished by acid lavas.—

Several of the islands, which lie very much scattered to the south of the Galápagos, have been visited by Lopez: he found *Sala-i-Gomez* to be 30 meters high, its major axis only 1,200 meters long, and the isthmus which connects the two halves of the island in the middle only 120 meters broad: the great waves of the equinoctial storms probably wash right across the island. It consists of porous basalt with olivine, but a white earth, produced by decomposition, and pitchstone are also mentioned.

*Mas-a-Tiera* and *Mas-a-fuera* are two much larger islands; the latter is formed by a single volcanic mountain, 1,837 meters high[2].—

The region of the South American Andes, with its long and lofty mountain ranges, its imposing volcanos, frequent earthquakes, and littoral terraces, has been made the subject of many investigations, resulting in numerous attempts to explain the formation of mountain ranges: it is strange that the contrast between the horizontal strand-lines and the inclined strata of the Cordilleras, and the contrast this involves between the formation of terraces and that of mountains, has not received more frequent attention.

The older views of C. Darwin on the relation between the elevation of the Andes and the formation of terraces and the alleged elevation of the continent during certain earthquakes of comparatively recent date have already been referred to in an earlier passage, together with the objections which may be urged against them (p. 104).

As the significance of the tangential movements became more clearly recognized, eminent authorities, such as Dana, saw in the Andes the result of a lateral pressure exerted on the continent by the subsidence of the geosynclinal of the Pacific. This explanation is, however, hard to reconcile with the deflexion of the chains towards Venezuela and Tierra del Fuego.

The assumption of considerable tangential movement also forms the chief basis of Kolberg's theory of 'out-thrusting by thrust-wedges,' put forward in explanation of the structure of Ecuador. It rests on the supposition that, during the contraction of the outer crust of the earth,

[1] T. Wolf, Ein Besuch der Galápagos-Inseln, 8vo, Heidelberg, 1879, p. 18 (Frommel and Pfaff, Samml. v. Vorträgen, I, pp. 259–300, map). A basaltic type is, it is true, also not wanting in Ecuador; cf. Gümbel, Sitzungsber. Akad. Münch., 1881, p. 365 et seq.

[2] Lopez, Esploracion de las islas esporádicas al occidente de la costa de Chile, Anal. Univ. Chil., 1876, pp. 649–673. The alleged island of Buchili (about lat. 28° 4′ S., long. 95° 4′ W.) was not to be found, nor was the island of Gray.

planes of separation are formed inclined very obliquely to the surface, thrust-planes as it were on a large scale, and the separated wedge-shaped fragment is moved and overthrust. This supposition accords better with views which might fairly be applied to certain European chains. But for Ecuador in particular Kolberg found it necessary to assume the existence of two wedges opposed to one another, and in this way he actually arrives at Élie de Beaumont's earlier theory of the formation of mountains by an 'écrasement transversal[1].'

The theory has repeatedly been put forward that the Andes have experienced a very considerable elevation in quite recent times, and a number of facts are adduced in support of this view. The saline deposits, which lie over 7,000, even 12,500 feet high, have been regarded as the direct result of evaporation of enclosed arms of the sea. But as regards the region to the east of the Andes many investigators since Woodbine Parish, and in particular Burmeister, Zeballos, and Schickendorf, have denied that the salinas of the Pampas are relics of this kind, and in the west also Pissis, for example, has found good reasons for decisively opposing this theory[2]. The fact that eight species of Allorchestes, a salt-water genus of the Amphipoda, live in lake Titicaca, cannot in any way be regarded as sufficient proof that the sea was connected with this lake in recent times; that is to say, that the sea-level stood from 12,000 to 13,000 feet higher than at present, or that the land has risen to this extent. The number of questions yet unsolved as to the means by which these animal forms are distributed is too great to admit of conclusions so comprehensive as this.

Orton's report that Loomis had found, one day's journey from Iquique, an old sea-coast with mollusca of existing species, 2,500 feet above the sea, has not as yet received confirmation of any kind[3].

Nor does the discovery of corals at Tilibiche in Peru, 2,900 to 3,000 feet above the sea and about 30 kilometers from the coast, justify us in such conclusions. These corals, according to A. Agassiz and Pourtalès, are attached to the surface of the rocks on which they grew, are converted into compact crystalline limestone, and have suffered almost complete obliteration of the internal structure. Apart from a form allied to *Millepora alcicornis*, two species were observed which are both new. *Isophyllia duplicata* belongs to a genus which is known in the Tertiary and in recent seas, but does not occur on the present shores of the Pacific. *Convexastraea*

[1] J. Kolberg, Nach Ecuador, 2. Aufl., 4to, Freib. im Breisg., 1881, pp. 209–221 et passim.

[2] A. Pissis, El desierto de Atacama; An. Univ. Chil., 1877, pp. 585–588.

[3] Orton, Andes and Amazon, p. 116. The theory of this author, based on a comparison of older barometric measurements, that the Andes are at present subsiding has been refuted by Reiss: Reiss, Sinken die Anden? Verh. d. Gesellsch. f. Erdkunde, Berlin, 1880, VII, p. 45 et seq.

*peruviana* represents a genus which as yet is only known from the Trias and Jurassic [1].

There thus appears to be no reason for assigning so extremely recent an age to these deposits.

In the south of Chili the most recent members of the Cretaceous and Tertiary formations are bedded against the Coast Cordilleras. They are faulted, but do not appear to have taken part in the folding. On the other hand, both in the north and south Cretaceous beds with Inoceramus occur, which have been folded along with the Neocomian. Intense folding occurs and also overthrusting towards the west, as for example in the Carboniferous of lake Titicaca [2], but overthrust outer borders, as in the Alps or Himálaya, have not as yet been observed.

The frequent earthquakes of the west coast are the expression of some great tectonic process the nature of which is unknown.

[1] A. Agassiz and L. F. Pourtalès, Recent Corals from Tilibiche, Peru, Bull. Mus. Comp. Zool., Cambridge, 1876, III, pp. 287–290; Am. Journ. Sc., 1876, 3rd ser., XI, p. 499.
[2] D. Forbes, op. cit., p. 49.

## *CHAPTER X*

# THE ANTILLES

The three series of islands. Cuba. Haiti. Jamaica. Puerto Rico to Barbados. The Cordillera of the Antilles. Comparison with the border of the western Mediterranean. Earthquakes.

In Central America the strike of the ancient formations does not follow the course of the elongated isthmus between the northern and southern continent, but runs transversely across it. This, at least, is the case whereever the strike has been precisely determined, and is particularly well shown in Guatemala, where an important segment of a unilateral chain occurs with a trend to the west-south-west (pp. 90–91). This chain commences in western Honduras, and its direction is indicated more or less exactly by the longitudinal valley of the Rio Motagua. Here we shall depend chiefly on the accounts of Dollfuss and Mont-Serrat, since Seebach's observations have only been published in abstract [1].

The most southerly zone consists of several fairly extensive exposures of granite, which have been observed to the north and south of the town of Guatemala, and south of the Rio Motagua to far beyond Zacapa. This is succeeded towards the north by a broad zone of mica-schists, further on by another of talc-schists, and these, passing to the south of the Golfe Dolce, reach the sea at the Amatique bay and near Omoa in the gulf of Honduras. Conglomerate and sandstone of trifling thickness overlie them on the north, and these are followed, beyond the Golfe Dolce, on the Rio de Cajabon and further towards the north and north-west by a broad limestone range, the limits of which are unknown. The scanty fossil remains, which have been supposed to indicate the existence of Jurassic limestone, do not seem to me to afford sufficient proof of its presence.

Thus then a segment of a chain exists, which runs transversely across the isthmus from west-south-west to east-north-east; its most ancient component lies in the south-south-east, and is succeeded by the more recent zones towards the north-north-west. Durocher has named it the 'Système de Segovia [2].'

[1] A. Dollfuss et E. de Mont-Serrat, Voyage géol. dans les Républiques de Guatemala et de Salvador; Miss. scientif. au Mexique, &c., 4to, Paris, 1868.

[2] J. Durocher, Recherches sur les systèmes de montagnes de l'Amérique centrale, Comptes rend., 1860, LI, p. 44; also by the same, Études sur l'orographie et la géologie de l'Amérique centrale, op. cit., 1860, L, pp. 1170–1175.

These mountains are bounded on the south by a great mass of old volcanic rocks of various kinds, which form the greater part of the mountains of Salvador and all the more southerly chains of Guatemala. An oblique line of fracture follows the Pacific coast from the bay of Fonseca towards the west-north-west, and marks the principal line of the recent, and in part still active, volcanos of this region (p. 93, Fig. 5). To the west of the town of Guatemala it meets the direction of the mountain chain at an acute angle, cuts the chain off, and proceeds towards Mexico. Many of the largest of the volcanos, and among them the great cones of San Miguel, Acatenango, d'Atitlan, and others, rise within the region of ancient volcanic rocks.

*The Antilles* are formed by the summits of a mountain chain which separates the Caribbean sea from the Atlantic Ocean and the gulf of Mexico. A second arc running from Honduras through Jamaica and the south-west of Haiti appears to join the principal chain. Even the great deeps which occur in certain places, as, for instance, between Virgin Gorda and Anguilla, do not interrupt the continuous course of the mountain chain.

This uniform structure has already been pointed out by many observers; no one has done so more emphatically, or has given greater prominence to the relations of the Antilles with the continent of Central America, than the most distinguished authority on these regions, Karl von Seebach.

With the slopes of the Mexican plateau in the state of Oaxaca, says Seebach, the compact northern continent terminates. To the south and to the east of the isthmus of Tehuantepec, Central America commences, which already belongs to the island world of the Antilles. '. . . The mountain series of the Greater Antilles, which further to the east in Puerto Rico and San Domingo—the eastern part of Haiti—forms a single main chain, divides in the middle of the latter island, giving rise to a southern branch which proceeds through the elongated peninsula of Jacmel towards Jamaica and Honduras, and a northern branch which extends beyond Cuba towards Yucatan. . . . Is it merely a remarkable accident that the Sierra Maestra, consisting of crystalline schists and massive rocks and situated in the south-east of Cuba (where the Greater Antilles reach their greatest elevation of 2,338 meters above the sea), should run through the Cayman group, the bank of Misteriosa, the Viciosas, and Swan island to the depths of the gulf of Honduras, and that from the edge of this mountain ridges similarly constituted should rise abruptly and proceed with constant strike into the interior [1]?'

[1] K. v. Seebach, Central-Amerika und der interoceanische Canal, 8vo, Berlin, 1873, p. 11 et seq.; Sammlung gemeinverst. Vortr., published by Virchow and Holtzendorff, viii. Ser., Heft 183. The transverse course of the mountains has also been observed by

If, with Seebach, we now consider the two mountain ranges of Yucatan and Guatemala, which proceed to the north-east, simply as 'the most westerly excurrent processes of the mountain system of the Greater Antilles,' not only do the foregoing observations on the structure of Guatemala attain their full significance, but the truth of the view, indicated by Humboldt and strongly supported by Ritter, stands clearly revealed; and North and South America must be considered as two continents of fundamentally different structure, between which lies a third element, the region of Central America and the Antilles.—

The Antilles may be divided into several zones.

The *first, innermost zone*, which lies within the concavity of the arc, only appears in the eastern part, in the Lesser Antilles. It is wholly of *recent volcanic origin*. This zone is formed by the islands of Saba, St. Eustatius, St. Christopher (St. Kitts), Nevis, Redonda, Montserrat, the western half of the deeply incised Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent, the Grenadines, and Grenada. These islands form a continuous circular arc, and some of them include three to four eruptive centres—Martinique, according to Jonnès, even six.

The *next zone* comprises the great and rich *mountainous islands* of the Greater Antilles and the narrow but well-characterized border of the Lesser Antilles. The mountains are formed in complete accordance with the type of the Coast Cordilleras of the south and of the mountains of Venezuela. The oldest organic remains belong to the lower Cretaceous, and these are only represented by a few traces; on the other hand, purer and highly fossiliferous limestone deposits of the Turonian are present in this region, as in Trinidad and in north Venezuela. The Cretaceous system is followed here, as in Trinidad, by a largely developed series of Tertiary deposits, some members of which present an astonishing resemblance to their representatives in Europe. These deposits form the connecting link with the third zone.

To this second zone belong Cuba and Pinos island, Haiti Puerto Rico, the Virginian islands with St. Croix, Anguilla, St. Bartholomew, Antigua, the eastern half of Guadeloupe and a part of Barbados, and further the southern arc which runs through Jamaica. That part which lies in the Lesser Antilles forms a girdle running outside the volcanos.

*The third and outermost zone* comprises *only middle Tertiary or even more recent deposits*. It nowhere rises in mountain ranges, which can be properly so called, and is, indeed, as a rule quite flat, broader towards the north-west, narrowing away to the south-east. It includes the Bahamas, all the banks of trifling height which succeed as far as Natividad, then Anegada, Sombrero, Barbuda, and a part of Barbados. I should, however,

M. Wagner, Physisch-geographische Skizze der Provinz Chiriqui, Petermann's geogr. Mitth., 1863, pp. 281–299, pl. ii.

be inclined to include in this zone the whole peninsula of Florida, and perhaps even the level part of Yucatan.

This regular arrangement of the islands was already clearly recognized in its main features by Leopold von Buch. 'All the volcanic islands of the Antilles,' wrote the great geologist more than sixty years ago, 'follow one after the other in a continuous chain, uninterrupted by any islands which are not volcanic. On the other hand, there appears to the east of these islands, lying outside them next the great ocean, another series of islands, somewhat less clearly marked, which exhibits only a few traces of volcanic phenomena, and contains no active volcanos. This is an extremely remarkable fact[1].'

The region which I propose to discuss in somewhat greater detail is the second or median zone.

*Cuba*, as we have already seen, attains its greatest elevation in the Sierra Maestra in the south-eastern part of the island, between Cabo de Cruz and Santiago de Cuba. The Pico Tarquino measures 2,338 meters in height. To the south the chain descends steeply to the sea; it runs from west to east and east-north-east, and its strata dip to the north. According to Cía, granite is exposed at several places along the south foot of the chain, but higher up it consists of an alternation of thinly stratified green sandstone with grains of felspar, dark shales, a breccia of limestone and shale, and finally beds of limestone of no great thickness. This series is followed by a thick breccia, the matrix of which is described as dark diorite or diorite porphyry[2]. A dark amygdaloid rock is associated with this breccia. A rock of similar nature occurs on many of the West Indian islands; English geologists have named it 'blue-beach.' North of Santiago de Cuba it extends to the east and west over the north flank of the Sierra Maestra, and is succeeded in the valley of the Rio Cauto by flat-lying Tertiary deposits which extend to the neighbourhood of Holguin.

Near Holguin we meet with an eruptive rock containing felspar and amphibole; at other places a true syenite occurs, and in immediate contact with these a band of serpentine, which, according to the concordant statements of Cía and Castro, extends from this point through the whole island; passing Puerto Principe it runs nearly as far as Havana, and into the most westerly part of the island, which trends west-south-west. This long band of serpentine is accompanied, particularly on the north, by a number of bands of light-coloured hard limestone. It nowhere attains heights of much importance, but nevertheless forms the watershed through the middle of the whole island; it is the seat of the mineral treasures of Cuba, and contains copper, chrome-ironstone, and gold: sandstones

[1] L. v. Buch, Physikalische Beschreibung der canarischen Inseln, 4to, 1825, p. 400.

[2] Policarpo Cía, Observaciones geológicas de una gran parte de la isla de Cuba; Revista mineral., 1854, V, pp. 365, 393, 420, 451.

resembling Flysch are not wanting, and from Holguin as far as Havana asphalt and petroleum are known to occur[1].

The occurrence of the serpentine near Havana was observed by Humboldt. The neighbourhood of this town has been described by Salterain. The north coast is here, as in so many other places, bordered by flat-lying Tertiary limestone, which in some places presents a surface like the Karst, and in others weathers into a layer of red earth. Within this border rise long ridges of folded beds, consisting of glauconitic siliceous limestone, marl, and sandstone devoid of fossils. In these rocks the asphalt occurs; by their decomposition they form the soil of the richest and most fertile parts of the island. The long low ridge of serpentine accompanied by ancient eruptive rocks rises out of these glauconitic deposits; it is visible in the harbour of Havana itself as a sombre mass, destitute of vegetation[2].

According to Castro, gneiss, talc schists, and dark limestone of an earlier period crop out to the south of the long ridge of serpentine in the Sierra de Cumanayagua, west of the port of Trinidad.—

Various opinions have been expressed as to the age of the sediments of Cuba; the black clay-slates and the quartzites of Mantua in the west of the island, on the north side of the Sierra de los Organos, have been attributed to the Palaeozoic, but up to the present I know of no fossils either from Cuba or any other of the West Indian islands which would indicate with certainty deposits older than the Cretaceous. Hippurites have been found in many places in the light-coloured limestone of Cuba: among the more recent horizontal beds the Orbitoides limestone must be mentioned, which occurs also in Florida and in many of the other islands; its age has already been pointed out (p. 282).

*Haiti.* The west of Haiti is but little known, but for the middle and the whole eastern part of the island we have the excellent monograph by Gabb on the structure of San Domingo[3].

Within the dominion of this Republic the direction of the mountains is also to the east-south-east, and the elements which enter into their composition are the same as in Cuba. The Flysch-like shales, limestones, and

[1] M. F. de Castro, Pruebas paleont. de que la isla de Cuba ha estado unita al continente americano y breve idea de su constitucion geológica; Bol. Com. Mapa Geol., 1881, VIII, pp. 357-372. For the more recent deposits see W. O. Crosby, On the Elevated Coral Reefs of Cuba, Proc. Boston Soc. Nat. Hist., 1882, XXII, pp. 124 et seq.

[2] P. Salterain, Apuntes para una descripcion fisico-geológica de las jurisdicciones de la Habana y Guanabacoa; op. cit., 1880, VII, pp. 161-225, map. The fossils from the neighbourhood of Havana, which were described some time ago by Lea, show that Mesozoic remains are not wanting; these do not, however, prove the presence of the Jurassic system: I. Lea, Notice of the Oolit. Formation in America, Trans. Am. Phil. Soc., 1840, 2nd ser., VII. pp. 251-260.

[3] W. M. Gabb, On the Topography and Geology of Santo Domingo; Trans. Am. Phil. Soc., Philadelphia, 1873, new ser., XV, pt. i, pp. 49-259, maps.

sandstones, the 'Sierra Group' of Gabb, form several parallel ranges; they have furnished only a few badly preserved fossils (Ammonites, Trigonia, and others) which have a Cretaceous appearance, and at one locality west of San Domingo, near Azua in the bay of Ocoa, some petroleum is found. Bands of rock resembling serpentine appear in these deposits, and Castro observes expressly that he has met on Haiti with the continuation of the serpentine of Cuba. Several ridges of syenite and other massive rocks form the heights of the Cibao mountains, which are said to reach an elevation of 8,000 feet.

The general structure of the Republic of San Domingo is somewhat as follows:—On the extreme north-east coast sandstones and shales crop out, especially near Cabo Frances and in the peninsula of Samaná, where they attain a greater development. We may probably regard them as forming the northern side of a synclinal with an east-south-east strike, since the Sierra of Monte Christi, which follows towards the interior, is entirely Tertiary, as is also the great longitudinal valley which runs right across the island from the bay of Manzanilla to the bay of Samaná. At the foot of the lofty Cibao mountains, which now follow towards the south, we still find Tertiary deposits.

The first heights of the Cibao mountains consist again, at least from Sabaneta eastwards, of sandstone and shale, and it is these alone which, advancing eastwards, form the mountain chain of the peninsula of Seybo, while the massive rocks which crop out from beneath them terminate towards the east above the town of San Domingo. Dykes of the massive rocks are intruded into the sediments, and form the upper parts of the Cibao monntains. Towards the south, near the bay of Ocoa, sandstone and shales again appear; the greater part of the south coast probably consists of these, and so do the two peninsulas which project to the west, i. e. towards Cuba.

*Jamaica* is now very well known, thanks to the efforts of the earlier English explorers, and in particular to the surveys made by Sawkins and Browne [1]. The Tertiary deposits here occupy a larger part of the surface than in Cuba or Haiti. The strike is very nearly the same. The west of the island is hilly and formed of Tertiary beds; the greater heights, however, are found in the eastern part, where the Blue mountains rise to more than 7,000 feet. They consist of the same rocks as the Cibao mountains of Haiti; syenite, granite, and diorite are exposed chiefly on the south-west side. The 'Metamorphosed Series,' which is nothing else than the Flysch-like deposits

[1] J. G. Sawkins, Reports on the Geology of Jamaica, or Part II of the West Indian Survey, 8vo, Lond., 1869, in particular pp. 26 et seq.; also L. Barrett, On some Cretaceous Rocks in the South-Eastern Portion of Jamaica, Quart. Journ. Geol. Soc., 1860, XVI, pp. 324–326; M. Duncan and G. P. Wall, A Notice on the Geology of Jamaica, op. cit., 1865, XXI, pp. 1–15.

of the other islands, constitutes the upper parts of the chain. This series is folded and crops out again towards the centre of the island from beneath the younger deposits, but with a much diminished height. Above it lie the already mentioned fossiliferous beds of the middle Cretaceous. Sawkins estimates their thickness at from 500–600 feet. According to this observer, the remains of very large Radiolites, firmly incorporated with the limestone, and Barrettia, a remarkable genus of Rudistes, are confined to the lower part of the series, while the fauna with Actaeonella and Hippurites, which so strongly recalls the Gosau beds in the eastern Alps, is found above.

Our knowledge of *Porto Rico* is unfortunately restricted to a very short note, which Cleve has included in his instructive description of the structure of the islands which follow to the east. The strike here appears to be directed more towards the east; the same rocks, which have been already discussed in Haiti, again crop out here [1]. They lie within a narrow selvage of recent deposits which border the north coast, and continue onwards to the *Virgin islands*.

These islands are separated from one another and from Porto Rico only by shallow sea, and Cleve has clearly shown how the several zones of rock are continued with an east to west strike through the various islands of the group, thus proving its tectonic unity. In the south we find a zone extending from St. Thomas and St. John through Norman and Peters islands, composed of older eruptive rocks, which are described as 'felsite with subordinate blue-beach.' A similar zone runs in the north of the archipelago to the north of Tortola and through the northern half of Virgin Gorda. Between these two lie zones of 'blue-beach' with the same strike, which are accompanied by shales, quartzite, and limestone altered and steeply upturned.

In a zone which appears to occupy a more or less median position we meet near Coki Point on St. Thomas with *Actaeonella laevis* and other fossils of the middle Cretaceous. We might almost suppose that the entire archipelago represents a single great synclinal, the most middle and recent member of which would be the strata with Actaeonella [2].

*Anegadd*, the most northerly of the Virgin islands, is an exception, and does not form part of the synclinal; we have already mentioned that it is quite flat and belongs to the outer zone.—

To the south of the island of Vieque and the southern Virgin islands the sea bottom suddenly descends to a profound depth. The island of

[1] P. T. Cleve, On the Geology of the North-Eastern West India Islands, Svensk. Vetensk. Ak. Handling. 1870, ny föld, IX, 57 pp. and maps; Puerto Rico, pp. 14, 15; also Annals N. York Acad. Sc., 1882, II, pp. 185 et seq.

[2] Cleve, op. cit., pl. ii, fig. i. Woodward also mentions *Actaeonella laevis* from St. Thomas in Quart. Journ. Geol. Soc., 1866, XXII, p. 570. For the island of Culebra see also D. C. de Guillerna, Memoria del reconocimiento del interior de la isla de Culebra, Bol. Soc. geogr. Madrid, 1880, VIII, pp. 23–47, in particular p. 35.

*Sainte-Croix*, which lies close to these islands, is said to be separated from them by depths of more than 12,000 feet. Nevertheless the same rocks reappear here. They occupy chiefly the north part of the island, and appear to descend along the coast abruptly into the sea to a depth of about 6,000 feet; the south of the island is Tertiary.

To the east of Sainte-Croix begins the great volcanic arc which runs to the south. The ash cones rise here to a height of 4,000 feet. The next series of islands on the east, through which the rocks of Cuba and Haiti are continued, rises to a height of 1,400 feet in a single instance only; for the rest the height varies between 200 and 500 feet.

On the west coast of *Anguilla* the older eruptive rocks and the stratified deposits of the great islands make their appearance over a trifling area only; they contain copper, and form some of the surrounding reefs[1].

These rocks likewise form the south part of *St. Martin*, crop out on *St. Bartholomew* near the town of Gustavia, and form the higher parts of the island[2]. On *Antigua* also the highest ridges are formed of greenstone, amygdaloid, and porphyry[3].

It has long been known that on *Barbados*, as on Trinidad, petroleum wells up from the ground in great quantity.—

It follows from the preceding observations that the whole of the middle or principal zone of the West Indian islands, from Cabo San Antonio at the western end of Cuba, through Jamaica, Haiti, Porto Rico to Barbados, is composed of the same rocks. Granite and in places gneiss-like rocks, older eruptive rocks, the peculiar blue-beach, serpentine, glauconitic sandstone, and then light-coloured limestone, the age of which, so far as it can be definitely determined by organic remains, is Cretaceous, form the visible remnants of a once continuous mountain range. It is the same series of rocks as that which forms the island of Trinidad, the northern chain of Venezuela, the chains of Merida and Bogota with their southern continuation, and finally the whole series of the Coast Cordilleras down to the southernmost point of the South American continent.

It is the same series of rocks which we meet with in many parts of Greece, in Crete and Cyprus, in many parts of the Tauric Armenian syntaxis, in the east of Afghanistan, on the Andaman and Nicobar islands. At the same time the striking resemblance to certain regions of the European Flysch is very remarkable. T. Wolf says that they are 'rocks

[1] Sawkins, Reports, &c., Append. I, Geological Report on the Island of Anguilla, pp. 257-261. Of several older descriptions I will only mention one treatise, which however is admirable for its time: W. Maclure, Observations on the Geology of the West India Islands from Barbados to Santa Cruz inclusive, Journ. Acad. Nat. Sciences, Philadelphia, 1817, I, pt. i, pp. 134-149.

[2] Cleve, op. cit., pp. 22 et seq.

[3] P. M. Duncan, On the Fossil Corals of the West India Islands, pt. i; Quart. Journ. Geol. Soc., 1863, XIX, pp. 408-410.

like Flysch and Nagelflue,' which, to the south of Chimborazo as far as Alansí, form the western Cordillera of Ecuador from foot to summit[1]. The petroleum springs recur in the lower Cretaceous Flysch of the Carpathians, and the long ranges of serpentine reappear in the Flysch of the north-east of Bosnia, in Euboea, and very many other places.—

We may henceforth speak of this series of islands as *the Cordillera of the Antilles.* Its course describes an arc. Towards the west it appears to divide into several branches in virgation, as has been shown by Seebach. One branch runs from the south of Haiti through the peninsula of Jacmel and the Blue mountains of Jamaica towards Honduras, another from the Cibao mountains of Haiti, across the Sierra Maestra of Cuba, towards the Amatique gulf in Guatemala, and thence crossing the isthmus reaches the line of the great volcanos. It is possible that a third branch is indicated by the Sierra de Cumanayagua in the centre of the island of Cuba.

The Cordillera is bordered on the north-east and east by Tertiary and even younger marine deposits, among which we have already mentioned in an earlier passage (p. 282) the coral beds of Castel Gomberto and the Orbitoides limestone, which corresponds to the lower limestone of Malta. Which of these members have shared in the folding, I have not been in a position to determine with complete certainty from the accounts at my disposal; but in any case, the recent deposits end abruptly against the slopes of the folded range and lie flat upon them, and their arrangement is similar to that of the descending series near Suez, that is to say, the younger deposits lean against the older at a diminishing height above the sea. These horizontally stratified sediments of recent age, mostly limestone, form not only the border of the great islands, but also some small flat islands with very steep cliff-like margins lying between the fragments of the Cordillera, as for instance the island of Mona between Haiti and Porto Rico[2]; of these sediments also the whole outer series of low islands consists, namely a part of Barbados, Barbuda, Sombrero, Anegada, and the fragments of the great Tertiary 'plate' as far as the peninsula of Florida (p. 283).

The arrangement of the volcanos on the inner side of the Cordillera precisely corresponds to that of the volcanos of the Apennines and the Carpathians; it is the result of in-break on the inner side of the arc. The border of the Caribbean sea presents a structure similar to that of the western Mediterranean, in complete contrast to that of the South American continent. We may even assert that the Caribbean sea as regards the nature of its border stands in a relation to the Mexican gulf, which

[1] T. Wolf, Neues Jahrb. f. Min., 1880, I, p. 268.

[2] D. I. Nuñez Zuloaga, Memoria descriptiva de la isla de la Mona, Bol. Soc. geogr. Madrid, 1879, VII, pp. 226–238, map; and Tejada, Reconocimiento de la isla de la Mona, op. cit., 1880, IX, pp. 81–93.

presents a remote resemblance to that existing between the western and south-eastern parts of the Mediterranean. The Caribbean sea is framed to north and east by the broken inner side of a mountain range, which in the east has allowed a series of volcanos to appear on its fractured border. Although a bending round of this chain from Barbados to the east-west direction of Trinidad and the mountain chain of north Venezuela has not been demonstrated, yet we find that this latter chain also turns its broken inner side to the sea. It is the same in Italy, in the north-west of Africa, and on the south coast of Spain. The gulf of Mexico lies outside the Cordillera of the Antilles; it has been produced by collapse in the foreland; its outline is not influenced in any visible manner by the course of the mountain-folds, unless perhaps in the west by the approach of the Mexican ranges to the coast of Vera Cruz. In like manner the southern part of the eastern Mediterranean has been produced by collapse in the desert table-land, although its outline is not indicated in advance by mountain ranges. It is true that in the northern part of the eastern Mediterranean another circumstance is added: the Tauric arc has broken down, and strange to say it is precisely in this region that we find two great islands, Crete and Cyprus, which present a striking resemblance to the fragmentary arc of the Cordillera of the Antilles. These two islands are also fragments of an arc; this fact is as clearly manifest in their outlines as in Cuba or Haiti, and they consist mainly of the same rocks as the Greater Antilles, namely of serpentine with chrome-ironstone, Flysch, and Cretaceous limestone, while granite furnishes the foundation.

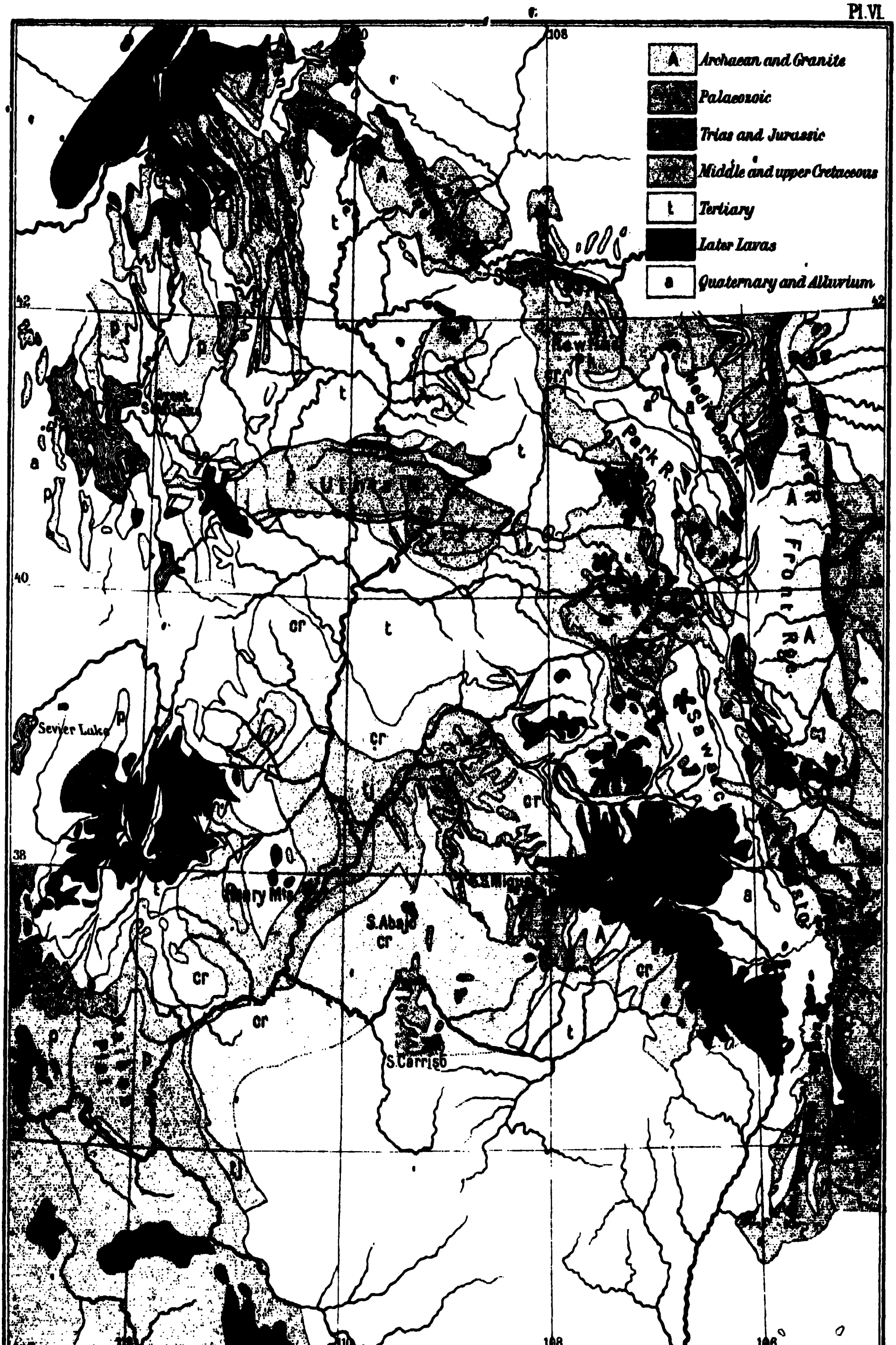
Just as the shores of the western Mediterranean in Calabria, at Cabo di Gata, and other places are frequently visited by earthquakes, so too is the neighbourhood of the Caribbean sea. Caracas and Cumana on the north coast of Venezuela, Guadeloupe among the volcanic islands, Port Royal in Jamaica have attained a lamentable celebrity. Numerous treatises have already been published on this subject, but up to the present I have been unable to recognize any relation between the phenomena. Salterain has shown that two distinct seismic regions are present in Cuba [1]. The first, distinguished for many centuries by great earthquakes, lies near Santiago de Cuba and belongs entirely to the east side of the island. A second is indicated by the earthquakes of the Cordillera of Vuelta-Abajo; these began in the night of the 22nd to 23rd of January, 1880,

[1] P. Salterain, Ligera reseña de los temblores de tierra ocurridos en la isla de Cuba; Bol. Com. Mapa Geol., 1883, X, pp. 371–385. It was the earthquakes of the east of Cuba which suggested Poey's remarks on the connexion between earthquakes and cyclones, the importance of which has been pointed out above in discussing the Deluge: A. Poey, Sur la force ascensionnelle qu'exercent les ouragans à la surface du sol, comme pouvant donner lieu à la production des tremblements de terre, in Poey's Supplément au tableau chronologique des tremblem. de terre ressentis à l'île de Cuba, from the Nouv. Ann. d. Voyages, 8vo, Paris, 1855, pp. 10–21.

and continued until the month of May of the same year. The shocks travelled across the most westerly part of the island, which is very narrow, and in a direction from south-west to north-east or west-south-west to east-north-east, over a fairly well-defined area which is bounded by the meridians of Las Mangas and Sta. Cruz de los Pinos. About the same time a new crater formed far from the island of Cuba in lake Ilopango on the great line of volcanos, which runs along the Pacific coast through San Salvador (p. 91). Rockstroh's account shows that the concussions began there in the last days of 1879, and on the 20th of January, 1880, at 11 p.m., during violent explosions a great column of vapour rose from the lake, and on the following morning the new island began to appear in its midst; on the afternoon of the 23rd of January the activity increased, and in February the new volcano had built itself up. It is composed of rhyolite; the concussions continued for a long time subsequently.

From the close correspondence in time and direction Salterain and Viñes concluded that some causal connexion existed between the eruption in lake Ilopango and the transversal shock of Vuelta-Abajo. The confirmation of this opinion must depend on future observation.

On the transverse fissures of the great volcanic line, which extends from Costa Rica to beyond Guatemala, the eruptive activity advances in the direction of the Pacific Ocean. As we mentioned above the movement takes place rather rapidly, and several new volcanos have been formed even during the last century.




The Virgation of the Rocky Mountains.

(See Cap XI. Note 1)

# CHAPTER XI

## NORTH AMERICA [1]

The foldings in the east. Prairies and Black hills. Division of the mountain ranges of the west. Rocky mountains. Uinta mountains. Wahsatch and mountain chains on the Snake river. Colorado plateau. The table-land of Utah and the grand cañon of Colorado. Basin ranges. Sierra Nevada. The Coast Cordilleras and lower California. The west of Canada. Summary.

*The Folding in the East.* The east of the North American continent, from the mouth of the St. Lawrence down to Alabama and Georgia, bears witness to great processes of folding, which at different times, but chiefly during the Palaeozoic period, have affected this important part of the earth's crust. The course of the folds, apart from deviations to be discussed presently, is directed generally from north-east to south-west, and the tangential force has always acted from the Atlantic Ocean towards the existing continent. Great faults have ensued; especially great longitudinal fractures which follow the strike of the folds, and, with a throw of vast extent, attain an extraordinary length. The geologists of the Pennsylvanian survey, who have traced the course of these disturbances with great precision, on account of their importance in relation to coal-mining, have estimated the subsidence produced by them at 20,000 feet in some cases, and in others at even much more. These subsidences do not, however, modify on the whole the picture so faithfully drawn by Henry Rogers many years ago, which represents Pennsylvania and Virginia, together with parts of Tennessee and other neighbouring states, as a vast folded region, a great fragment of the earth's crust impelled in one direction, which may be aptly compared with the Jura in Europe. And indeed each time we return to the works of this distinguished investigator we are filled anew with

[1] The little map of Pl. VI is only intended to depict approximately the relative position of the most important parts of the Rocky mountains, and the distribution of the sediments on the Colorado plateau. On account of the small scale it was impossible to attempt a correct representation of the Wahsatch range, of the narrow folded chains to the north of the Bear lake, or even of the edges of the flexures. The Laramie is throughout assigned to the Cretaceous. The region of lake Utah has not been coloured. For the northern part, as far as 42° 15′, the map drawn up by Peale, St. John, and Endlich, and edited by Hayden, has been followed; for the next zone, to the north boundary of Colorado, and for the western part of the Uinta range to the Salt lake, the maps of Clarence King; for the eastern part of the Uinta, Powell; for Colorado, the map by Hayden; the high table-land of Utah, together with the neighbourhood of the cañon, has been represented according to Dutton, and north Mexico according to Stevenson.

astonishment, that he should have been able, at such an early period, to arrive at so correct a conception of the structure of mountain regions of this kind [1].

A great number of saddles and basins of great length are present. The felsitic rocks, which on the east coast of Nova Scotia extend along the Atlantic Ocean in the middle of the anticlinals, are Archaean, as is shown by the superposition of strata containing the primordial fauna. On the island of Scatari, which may be regarded as the furthermost extension of cape Breton towards the ocean, the strike, according to Fletcher, is S. 82° to 88° E.; near Rochford on the south-east coast of cape Breton, N. 74° E.; further to the south on the same coast near cape Gabarus, N. 46° E.—as though the general strike of the anticlinal folds, directed approximately south-south-west or south-west, tended, on approaching this part of the ocean, to turn more towards the east. Even, however, in this remote portion of the great system of folds, sediments of the Carboniferous period lie transgressively over the anticlinals of the Archaean—a proof of the remoteness of the period during which the movement of folding took place [2].

On the north coast, immediately to the north-west of Scatari, other anticlinals strike in a north-easterly direction out to sea; this direction also determines the outlines of Nova Scotia and cape Breton.

The folds now proceed across the whole breadth of New Brunswick as far as the eastern shore of the lower St. Lawrence, the direction of which is determined by their course, but on the island of Anticosti they flatten out to so great an amplitude that the stratification along the coast appears to be horizontal over intervals miles in length, and the straits of Belle Isle, which separate Newfoundland from the continent, are bounded by horizontal strata on both sides. Prince Edward island consists, as we shall see directly, of much younger rocks, and the strait of Canso, which separates cape Breton from Nova Scotia, is a transverse furrow, cutting across the folded region like Matyushin Shar in Nova Zembla (p. 504) [3].

[1] H. D. Rogers, Rep. Brit. Assoc., 1856, Cheltenham, and The Geology of Pennsylvania, 4to, 1858; in particular, On the Laws of Structure of the more disturbed Zones of the Earth's Crust, and Classification of the several Types of Orographic Structure visible in the Appalachians and other Undulated Mountain Chains, op. cit., II, pt. ii, pp. 885–941. Subsequently an attempt has even been made with the help of more exact observations to express the extent of the lateral contraction in figures. Attempts of this kind are accompanied by great difficulties and a high degree of uncertainty; Claypole quotes the figures 65 : 100 as representing the proportion of the present to the original breadth: Nature, 1884, p. 531.

[2] H. Fletcher, Report on the Exploration of Cape Breton, Nova Scotia, Rep. Geol. Surv. Canada for 1875–1876 F, 1876–1877, pp. 454–513, 1877–1878 F, pp. 9 et seq., maps; and by the same author, Report on Part of the Counties of Richmond, Inverness, Guysborough, and Antigonish, Nova Scotia, op. cit., 1879–1880 F. A sketch map in Dawson, Acadian Geol., 8vo, Lond., 1868.

[3] J. Richardson, Report, map showing the distribution of the lower Silurian rocks

A great part of the anticlinals and synclinals, which extend through New Brunswick as far as Gaspé, has been mapped during the last few years by the Geological Survey of Canada; I must content myself with observing that their strike is directed to the south-west and south-south-west, and that they are continued towards Maine. Particular difficulty has been found in deciphering the structure to the south of Quebec; but the investigations of Selwyn on Canadian territory and those of Wing and Dana in Vermont, and as far south as the neighbourhood of New York, have shown that over the whole of this great distance the tectonic features of the country strike almost precisely due north and south [1].

While, however, these meridional lines, which appear to be partly folds and partly longitudinal fractures, run to the south on the east of lake Champlain and the valley of the Hudson, a series of folds soon comes in, which begin with the Catskill mountains, north-north-west of New York, and take a direction to the south-south-west; on the north-west of Philadelphia, near Pottsville and Harrisburg, we see these folds, in ever increasing development and with a rich accompaniment of Carboniferous sediments, pass in a great sigmoid flexure from south-south-west and south-west, first to nearly due west, and then after some distance back to south-west. With this strike they form the Alleghany mountains, and are continued into Alabama and Georgia. This deflexion of the strike takes place in Pennsylvania, and in this region the folds are cut across by most of the tributaries of the Susquehanna; it was here that H. D. Rogers pursued his investigations into the formation of mountain chains by unilateral folding. The new surveys made under Leslie's direction have furnished a treasure-house of observations on the details of the form and the course of the folds, on the thrust-planes in the over-folds, the longitudinal fractures, and in general on all the details of the structure of the country. In the south-eastern district situated on the inner side of the folded system, the coal is converted into anthracite; in the outer folds, as on the flat-lying beds of the western regions, it is bituminous. A similar phenomenon, as is well known, is met with in Belgium.

Without following the further course of the folds through Virginia,

between Chaudière and Trois-Pistoles, Rep. Geol. Surv. Can. for 1866-1869, pp. 133-157; W. E. Logan, Geol. of Canada, 8vo, 1863, pp. 2, 287, 864 et passim; for Anticosti, J. Richardson, Rep. for 1853-1856, pp. 191-245 et passim.

[1] For North Brunswick I will only mention R. W. Ells, Report on the Geology of Northern and Eastern New Brunswick and the North Side of the Bay of Chaleurs, Rep. Geol. Surv. Can., 1880-1882 D, map; and by the same, Report on the Geology of Gaspé Peninsula, op. cit. DD; further, for the region Quebec—New York, A. R. C. Selwyn, The Quebec Group in Geology, Proc. and Trans. Roy. Soc. Canada, I, Montreal, 1883, sect. iv, 1882, pp. 1-13; and J. D. Dana, An Account of the Discoveries in Vermont Geology of the Rev. A. Wing, Am. Journ. Sc., 1877, XIII, pp. 332-347, 405-419, and XIV, p. 36, and by the same author, On the Relations of the Geology of Vermont to that of Berkshire, op. cit., 1877, XIV, pp. 37-48, 132-140, 202 et seq.

I will briefly describe, according to Elliott's observations, their southern termination, although it is precisely in this region that many problems present themselves, which appear to still await solution[1].

The Blue range extends to the south-west as an important chain of heights; in the west of North Carolina it rises to 6,700 feet in the Black Dome, exceeds 4,000 feet in Caesar's Head on the north-west boundary of South Carolina, and disappears between Jasper and Cartersville north-west of Atlanta in Georgia. A second chain, the Smoky mountains, runs on the west, nearly parallel to the Blue range, but bends to the south on reaching the northern boundary of Georgia; it forms in this state a number of important summits, as for instance Sharp mountain, and its last peaks rise between Cartersville and Alatoona. In this region the ramifications of both chains unite, and in northern Georgia a wedge-shaped more elevated area remains enclosed between them. These chains consist of gneiss and of primordial and lower Silurian deposits. The enclosed area is synclinal in structure. The eastern border, the Blue range, is a monoclinal; its beds dip to the west, while on the east it is bounded by a scarp, which probably corresponds to a fault, for strata of lower Silurian age also crop out in the lower-lying ground on the east, as though this had suffered a considerable subsidence. The strata of the Smoky mountains west of the enclosed and elevated area dip beneath the latter, but they are followed further to the west by a number of other folds, which include younger members of the Palaeozoic series, and continue their course to Alabama, where they disappear beneath the great Cretaceous transgression.—

In this vast folded region of eastern America the transgressive position of some of its members—especially well exhibited in the north—shows that it had already commenced to acquire its existing structure during the Silurian aera, and that the movements then in progress must have continued to act for a very long period, or else have been several times repeated. Lying on this ancient folded complex are long bands and isolated masses of a red or grey sandstone of Mesozoic age, which, on the evidence furnished by the plant remains it contains, is usually assigned to the Trias.

This formation is accompanied for the greater part of its extent by sheets and dykes of eruptive rock. It occurs near Prince Edward island, along the shore of the bay of Fundy, in the valley of Connecticut, through Massachusetts down to the neighbourhood of the sea, then in an exceptionally long strip from the lower Hudson through New Jersey, Maryland, and Virginia to North Carolina, and in other isolated localities.

[1] J. B. Elliott, The Age of the Southern Appalachians; Am. Journ. Sc., 1883, XXV, pp. 282-298.

The strata maintain a unilateral inclination for long distances, but folding does not appear to have been yet observed [1].

Towards the west the folded region in the east of North America is not separated by an overfolded border from an alien foreland, but the foreland is of the same nature as the mountains themselves; the folding flattens out towards the west very gradually, and Rogers believed, many years ago, that its last traces might be recognized even as far as the Rocky mountains. In front of the folds of the Alleghanies and running parallel to them from lake Erie far to the south-west, there rises an independent anticlinal, the Cincinnati Uplift, which is comparable in all essential features to the 'Parmas' of the Ural. It extends from the shores of lake Erie into Tennessee, and, according to Safford, it reveals the Devonian resting immediately upon the lower Silurian. Further to the west the folding completely dies away. In Michigan only a very slight inclination of the strata towards the middle of the great basin, which separates the lakes, is to be perceived, and the Coal-measures of Illinois and Missouri lie flat; in Kansas they dip to the west with a very slight inclination beneath marine deposits of Permian age.

The *Prairies and the Black Hills.* A vast inhospitable region, presenting all the signs of extensive denudation, devoid of considerable heights and continuous ridges, without any definite river system, and covered with numerous lakes of irregular outline, extends from lake Superior to the north-west, north, and north-east; it includes Hudson's bay, and is continued into the Arctic Archipelago. It is formed of Archaean rocks, supporting here and there flat-bedded Palaeozoic rocks. Bell has explored many parts of this region; his descriptions recall the Archaean 'platform' of Lapland [2].

Towards the west this extensive mass of ancient rocks is covered over by transgressive Cretaceous deposits, which form all the level country, extending onwards to the foot of the Rocky mountains, and through the whole centre of the continent down to Texas, and even beyond it as far as Mexico. The transgression begins, as in so many other regions, in the middle of the Cretaceous system. The members of this system, which have been distinguished in the plain, bear the following names: Dakota, Fort Benton, Niobrara, Fort Pierre, Fox Hill, and Laramie; the order being taken from below upwards. The lowest division, or the Dakota beds, frequently contains terrestrial plants, lignite, and remains of reptiles, but marine deposits are also present; most authors regard it as the equivalent of the European

[1] W. M. Davis, The Structural Value of the Trap Ridges of the Connecticut Valley; Proc. Boston Soc. Nat. Hist., 1882, XXII, pp. 116-124.

[2] R. Bell, Report on Hudson's Bay, Rep. Geol. Surv. Can., 1877-1878 C, and 1879-1880 C; Report on the Geology of the Basin of Moose River; Report on the Geology of the Lake of the Woods, op. cit., 1880-1882 C and CC, with maps, and other publications.

Cenomanian; the Fort Benton beds also afford in many places lignite and reptilian remains. The beds of Niobrara, Fort Pierre, and Fox Hill are exclusively, or at least chiefly, marine. The Laramie are frequently accompanied by coal beds and by the remains of Dinosaurus, but also by a poverty-stricken marine fauna, possessing but few species, some of which point to the influence of brackish water; true fresh-water deposits are also present. This stage is assigned by a few eminent authorities to the lowest part of the Tertiary; we place it on account of its Dinosaurus in the Cretaceous.

It is a very remarkable fact *that in the whole of the North American continent*, with the exception of a few littoral districts and the basin of the lower Mississippi, *no trace of a Tertiary marine submergence has been observed.* A long series of varied Tertiary deposits rests upon the Laramie stage, particularly to the west of the Rocky mountains, but they have been formed without exception in fresh water. Not less surprising is the vast extension of the inland waters of Laramie, for we find the deposits of this stage in the north on the Saskatchewan, and again in the south far below Santa Fé in New Mexico on the Rio Grande [1].

J. Richardson, Selwyn, J. W. Dawson, and G. M. Dawson have described the structure of the Cretaceous plain in the north.

The boundary of the Cretaceous region on the north has not yet been determined. G. M. Dawson informs us that from the upper tributaries of the Peace river, the Rocky mountains appear to trend almost due north, so that they meet the bend of the Mackenzie below its confluence with the Liard. At the same time remains of Devonian and perhaps Silurian deposits are known, which extend from the Clearwater and Athabasca towards the north-west as far as the western end of the great Slave lake. It would therefore appear that the Cretaceous deposits are considerably restricted or interrupted in this region [2]. But we shall probably never know how far they once extended over the denuded region to the east and north-east.

Lake Winnipeg lies entirely within the region of ancient rocks, but the Red river, shortly before discharging itself into this lake, appears to form a remarkable boundary, for, according to J. W. Dawson, the right or eastern bank of its broad marshy basin consists of Silurian limestone, the western,

[1] J. Stevenson, Note on the Laramie Group of Southern New Mexico; Am. Journ. Sc., 1882, XXII, pp. 370-372. On the east side of the Rio Grande to 150 miles below Santa Fé, with Ostrea, Corbula, and others, and with coal. Also White, Geographical Extent of the Laramie Group, op. cit., 1882, XXIV, pp. 207-209, and in particular op. cit., 1883, XXVI, p. 120.

[2] G. M. Dawson, Report on an Exploration from Port Simpson on the Pacific Coast to Edmonton on the Saskatchewan; Rep. Geol. Surv. Can., 1879-1880 B, p. 130.

however, of Cretaceous beds, over which we ascend by two great steps to the plain of the Prairies [1].

Further to the south, in Nebraska and Kansas, the Dakota beds lie flat on the Permian: the latter, also approximately horizontal, approach from the east, as the covering of the Carboniferous deposits, and with a scarcely noticeable inclination disappear beneath the Dakota beds.—

From the midst of the Cretaceous plain there rises between the two branches of the Cheyenne river a strange orographic mass, the Black hills of western Dakota. Its structure is of singular regularity. The highest point, Harney's Peak, 7,403 feet high, is situated to the south-east and a little to one side of the centre; it is a bold rugged mass of intrusive granite, and rises, surrounded by smaller intrusive masses, out of a region of Archaean mica-schist and clay-slate, which extends chiefly to the north-north-west. The Archaean rocks are steeply upturned and abraded; above them, in an encircling zone lies the primordial Potsdam sandstone, only 200-300 feet thick. Upper and lower Silurian, as well as Devonian, are entirely wanting, and the Potsdam sandstone is succeeded, with a deceptive appearance of concordance, by the Carboniferous limestone. This forms a second concentric zone, narrow in the east, broader in the west. Towards the interior it rises together with the sandstone in a scarped outcrop above the soft Archaean schists, and towards the exterior it descends all round in a flexure which is particularly steep towards the east. Newton and Jenney, from whose monograph on the Black hills the foregoing has been borrowed, lay particular emphasis on the fact that the top of the Carboniferous limestone forms a broad plateau, in which the strata are much less steeply inclined, while around the margin the dip is considerably increased; in this respect the structure is comparable with that of the Kaibab plateau (p. 130). The elongated space which is surrounded by the belt of Carboniferous limestone is about 140 kilometers long and more than 60 kilometers broad [2].

This great ellipse of Carboniferous limestone is surrounded by a depression formed of readily disintegrating red-coloured rocks. The first zone is red sandstone with gypsum, belonging perhaps to the Trias; the second consists of variegated sandstone and shale with fossils of the upper Jurassic. Thus we have here a marine member which is completely absent in the east of the continent. It becomes visible at a low level as we approach the Rocky mountains, just as the Mesozoic series is seen to become more complete in the Salt range of India as it proceeds towards the high chains beyond.

The hollow formed by the red rocks is surrounded by the rising scarp of the Cretaceous outcrop.

[1] J. W. Dawson, Observations on the Geology of the Line of the Canadian Pacific Railway; Quart. Journ. Geol. Soc., 1884, XI. pp, 378, 379.

[2] H. Newton and W. P. Jenney, Report on the Geology and Resources of the Black Hills of Dakota, 4to, Washington, 1880, atlas.

The axis of the great ellipse is not a straight line, but somewhat convex to the east; this is indicated by traces of prolongation of the mass towards the north-west and towards the south: in the first case these are accompanied by several outcrops of trachyte. The border of the Rocky mountains suffers a similar deflexion in the same latitude.

The plateau of the Carboniferous limestone appears to me too nearly horizontal to be described as a simple anticlinal or as a Parma of the Rocky mountains. After reading the description we are left rather with the impression that here too the surrounding plain has dropped along the flexures.—

We now return to the Cretaceous plain which gradually ascends towards the west, and approach the border of the Rocky mountains. We will, however, first cast a brief glance at the great mountain ranges of the west.

*Classification of the ranges of the west.* The vast mountain region of the west of North America is bounded on the east by the sharply defined foot of the Rocky mountains, and on the west by the Pacific Ocean, which penetrates in the gulf of California deep into the mountainous country, and towards the north even isolates considerable parts of it, such as Vancouver and the Queen Charlotte islands.

In the extreme north the eastern border of the Rocky mountains is very little known; from the upper Mackenzie to the upper tributaries of the Peace river it appears, as we have said above, to run nearly north and south; it then proceeds for a considerable distance far towards the south-south-east; in the west of Montana, beyond that point at which the Missouri leaves the mountains, it assumes a south-easterly direction, including the Big Horn mountains; then between latitude 44° and 43° N., in the south of Wyoming, it again turns due south. It follows this meridional course throughout the whole of Colorado along the meridian of 105° approximately, and in New Mexico, in lat. 35° 30′ N., between longitude 105° and 106° W. the chain disappears, having first been deflected a little to the south-south-west.

Recent volcanic rocks take part in the formation of these mountains; not only are they visible in all the more important parts of the chain, but in places they even advance towards the east beyond the foot of the Rocky mountains. In Oregon and Washington they cover particularly large areas.

Within the region of the United States three natural lines may be distinguished which divide the whole mountainous country into four more or less independent regions.

The first of these lines runs with a slight deflexion to the south-south-west from the fractured western border of the Wahsatch mountains, that is, from the eastern border of the Great Salt lake, towards the extremity of the Cañon of Colorado. The second line is marked by the abrupt

eastern border of the Sierra Nevada of California. The third line corresponds to the longitudinal valley of California, through which the Sacramento and the San Joaquin flow, and to the gulf of California.

The first region includes the Rocky mountains, the transverse chain of the Uinta, the Wahsatch mountains, and between these chains two great table-lands, that of the Green river north of the Uinta mountains, and the great Colorado plateau to the south of them.

The second region is that of the *Basin ranges*. A number of shorter folds running nearly in the meridian, and intersected at acute angles by mighty fractures, characterize this region. It comprises the numerous smaller regions of the west which have no outlet, but extends, though with some alteration in the strike, far beyond their borders.

The third region comprises the *Sierra Nevada* with its western foot-hills.

The fourth region is formed by the Californian *Coast ranges* with *lower California*, and here we shall again meet all the essential characteristics of the Coast Cordilleras of South America.

To this method of grouping, which has been proposed by distinguished American geologists, the objection may perhaps be raised that the Wahsatch mountains already exhibit in all essential features the structure of the Basin ranges, and must therefore be included with them; but there is an obvious convenience in bringing together the regions which surround the Green river and Colorado table-lands, and this probably suggested the classification, which will therefore be retained in the following pages.

*Rocky mountains.* Throughout the regions lying to the east of the Great Salt lake the succession of the strata is nearly identical with that of the east, and still more closely approaches that of the Black hills. The primordial sediments are known in many places. The Silurian deposits which rest upon them are, it is true, only represented, so far as we know at present, by isolated members. Still more scanty are the traces of the Devonian, which with comparative certainty may be assumed to be absent even over large areas. The deposits of the Carboniferous period on the other hand are present in great thickness, and the marine equivalents of the upper coal-bearing group of the east are particularly well developed; passage beds of Permian character also are not wanting.

The Trias is represented by red sandstone and gypsum, but in the north-western part of this region a fossiliferous marine group (the 'Meekoceras Beds') is intercalated into its lower part, which in the south-east of Idaho attains a thickness of some thousands of feet. The fauna recalls certain members of the Alpine Trias, but species also occur which have hitherto been regarded as Jurassic [1].

[1] A. C. Peale, Report on the Green River District, in Hayden, XI, Rep. U.S. Geol. Surv. for 1877, pp. 622–629, and Jura-Trias Section of South-East Idaho and West Wyoming,

The Jurassic formation corresponds to that of the Black hills; up to the present only a single subdivision, evidently upper Jurassic, has been recognized. Its resemblance to the Russian Jurassic will be considered later.

The Cretaceous system attains great importance, but its members are essentially the same on both sides of the Rocky mountains, beginning with the Dakota and concluding with the Laramie beds. In the interior of the mountains the whole of the Tertiary period is represented by fresh-water deposits only. Several divisions may be distinguished by means of the rich terrestrial faunas which they contain, and the presence of Coryphodon shows that the fresh-water deposits begin even in the earlier stages of the Eocene.

Thus between the Rocky mountains and the land to the east there exists no such difference as that between the Alps or Himálaya and their foreland. The stratified series of the east, from the Black hills onward, is increased by the introduction of a single member only of the Jurassic, to which is added in the north-west a marine member of the Trias. Yet it is noteworthy that the intercalation of these two marine formations takes place precisely in the same gap, between the Permian and Cenomanian, as that which, in the Alps and the Himálaya, receives the most important accession of marine formations foreign to the foreland.

We will now endeavour, with the assistance of Hayden's map of Colorado and the numerous treatises which exist on this subject, to trace the course of the Rocky mountains within the region of the United States [1].

Travelling across the prairie from the east towards the mountains we ascend very gradually over the surface of the Cretaceous beds to the considerable height of about 5,000 feet (Denver, 5,197 feet); the beds, which have so far lain horizontal in the plain, are now suddenly turned steeply upwards; the outcropping edges project in long 'hogbacks,' and forthwith there rises from them the great front range of Colorado, many peaks of which attain a height of more than 14,000 feet. These lofty masses are formed of Archaean rocks; the steeply upturned outcrops at their foot reveal a stratified succession, which in its main features is the same as that of the Black hills: there is here nothing to recall the zone of Molasse, of Flysch, or limestone which lies in front of the Alps. This absence of transitional foot-hills strikes every European geologist with surprise [2].

Bull. U. S. Geol. Surv., 1880, V, pp. 119–123; C. A. White, Fossils of the Jura-Trias of Southern Idaho, op. cit., pp. 105–117.

[1] F. V. Hayden, Geological Map of Colorado, in Hayden, X, U. S. Geol. Surv. for 1876.

[2] I will here refer the reader to the instructive description by G. v. Rath, Sitzungsber. Niederrhein. Ges. Nat. Heilk. Bonn, Sitzungsb. v. 7. Jan. 1884.

The chain consists of a considerable number of isolated masses or of great ridges of ancient rocks, which at the first glance recall the so-called 'central masses' of the Alps, or the mountain cores of the Riesengebirge. The arrangement of these features differs, however, from that met with in the European mountains (Pl. VI).

Already even in the extreme south the peculiar structure of the chains is known to occur as has been shown by Stevenson [1].

We have seen on the other side of the Atlantic how the branches of the Thian-shan, trending to the north-west, and the Mugodjars running north and south, all arise independently of each other from the table-land of the Ust-Urt: and now we find north-west and meridional chains similarly arising from the table-land formed by the great plains of the Llano Estacado, which extend from Texas towards New Mexico. Near Galisteo in lat. 35° 25′ N. these chains approach each other very closely, without, however, coming into actual contact. The most extreme north-westerly chain is that of the Placer mountains, south-west of Galisteo; but this belongs to another group of ranges, which will be discussed later. In this region we include none but the meridional ranges in the Rocky mountains.

Here, in the south, there are three principal ranges, which all begin in lat. 35° 30′ N. and trend to the north or north-north-east. The first of these, starting from the west, is the Sierra of Santa Fé; the second, which is the longest, bears successively the names Sierra de las Vegas, Sierra Mora, Sierra Taos, and Sierra Culebra—the last of these unites in Colorado with the great Sierra Sangre de Cristo; the third range, finally, Sierra Cimarron, is much shorter and buried to no small extent beneath the younger lavas, which make their appearance in the east. The first two of the ranges rise rapidly to a height of 12,000 feet; somewhat further north Culebra peak attains an altitude of 14,049 feet.

These mountains consist of gneiss, hornblende schist, and other Archaean rocks, on which rest Carboniferous deposits, beginning with a very thick conglomerate formed of Archaean boulders; the Carboniferous is followed by a series of Mesozoic strata, such as are generally exposed in the Rocky mountains, and these extend to the top of the Laramie; finally, there occurs near Galisteo a peculiar patch of Tertiary beds.

The Sierra de Santa Fé is bordered on the east side of its southern part by a fault which extends for some distance to the south beyond the extremity of the Archaean range; the Sierra de Las Vegas is also continued in the same direction, but in the form of an anticlinal fold.

Towards the east the chains are accompanied by trachytic flows, and

[1] J. J. Stevenson, Geological Examinations in Southern Colorado and North New Mexico; G. M. Wheeler, Rep. U. S. Geograph. Surv. West of the 100th Merid., III, 1881, 4to, maps.

especially by extensive basaltic sheets, which spread over the adjacent plain. The Laramie beds are still involved in the folding; but these volcanic formations are of much more recent age. Even well-preserved ash cones occur; one crater lies on the basalts of the Ocate-Mesa, and a second on the south-east side of the Turkey mountains; from the latter a lava stream has flowed into the previously excavated cañon of the Mora river.

Further to the north the short Sierra Cimarron disappears, and the lofty Sierra Culebra forms the outer border; the eastern foot of the latter is accompanied by a long rocky ridge known as the 'Stone Wall.' It is formed by the basset edges of steeply upturned Dakota sandstone. For a certain distance its strata are inverted and inclined to the west, then they become vertical, and finally dip to the east at a moderate angle beneath the plain.

Still further to the north, in about 37° 20′, the outcrop of the Dakota retires to the east, the Carboniferous zone becomes broader, and in front of the border of the Rocky mountains there rise two lofty summits, the Spanish peaks (13,620 and 12,720 feet), long ago the boundary marks of Spanish rule. These are the two great laccolites which have been discussed in an earlier passage (p. 149)[1].

Here, where the Sierra Culebra proceeds to the north-north-west to join the Sierra Sangre de Cristo, that very peculiar arrangement of the Archaean chains begins which characterizes the Rocky mountains. Plate VI only gives a very incomplete representation of it. In using this map we must carefully distinguish the Archaean rocks which form the high chains from those which are more deeply seated and exposed only by erosion, such as are found at the bottom of the Grand cañon of Colorado, to the west of the Sawatch range, and near the sources of the Rio Grande, as well as to the west of this river, where they make their appearance from below sheets of volcanic rocks.

From the combined labours of Hayden, Clarence King, Hague, Marvine, Stevenson, and other investigators, we arrive at the following results[2]:—

Each single range of Archaean masses runs from south to north, with a tendency to deviate to north-north-west or north-west. At the same time these various ranges or branches are so arranged side by side that they diverge from one another towards the west in virgation, while towards the east a nearly straight north to south line forms the common outer boundary of the mountains.

[1] My authority here is Endlich's map in Hayden, IX, Ann. Rep., 1875, pl. xvi.

[2] Hayden in Geol. Surv. Rep. for 1873, p. 19; A. R. Marvine, op. cit., pp. 131 et seq., pl. ii; C. King, U. S. Geol. Exploration of the Fortieth Parall., I, System. Geol., 1878, pp. 15 et seq.; A. Hague, op. cit., II, pp. 2 et seq.; J. J. Stevenson, Structure and Age of the Rocky Mountain System, in Wheeler's Report, 100th Parall., III, pp. 488 et seq.; further, A. C. Peale, Notes on the Age of the Rocky Mountains in Colorado, Am. Journ. Sc., 1877, XIII, pp. 172–181, 388; Stevenson, op. cit., pp. 297–299 et passim.

The first branch runs to the north, from the Sierra las Vegas, through the Sierras Culebra and Sangre de Cristo to the extensive mass of the Sawatch. The western half of Sangre de Cristo is faulted down, and the broad alluvial plain of San Luis extends here in its place; to the west of this lies the volcanic region of the San Juan mountains. Close to the north-west border of the Sawatch mountains lie the Elk mountains, which are completely overfolded to the south-west; the structure of these mountains has already been discussed (p. 164).

The second branch is formed by the Wet mountains, which rise to the east of Sangre de Cristo, then by the South Park range and Park range. The isolated anticlinal of Rawlin's peak appears to lie between this branch and the next.

On the long band of Palaeozoic deposits, which separate this branch from the preceding, lie the important galena mines of Leadville, and the surveys made by Emmons show that this band is traversed by great longitudinal faults with a downthrow to the west, i.e. towards the Sawatch mountains. Along the Mosquito fault in Leadville the downthrow amounts to 5,000 feet, along the London fault which follows it to 2,500 feet, and the same on the Weston fault; to the south of Leadville these fractures pass into flexures [1].

The third branch of the Rocky mountains consists of the broad and lofty Front range or Colorado range and Medicine-Bow range.

The fourth branch is formed by the low and flattened arch of the Laramie mountains, which strikes due north.

The eastern border of these lofty mountains emerges, as we have already said, unexpectedly from the plain, and the sediments of this plain outcrop in steeply upturned edges at their foot, like the Stone Wall on the east of the Culebra. A closer consideration of this eastern border shows that the southern extremities of the several branches are not joined continuously to one another, and thus there arise within the border a number of re-entrant angles all turned to the north-west, each of which marks the syntactic union of a new branch. The upturned basset edges then bend into these angles, as is particularly well seen in the outcrop of the Cretaceous formation; and Marvine has shown in connexion with this that in each of these branches the inclination of the strata is steeper on the west side than on the east, and, indeed, that the west side frequently passes into a fault.

A fine example of one of these re-entrant angles is afforded by Huerfano park between Sangre de Cristo and Wet mountains, that is between the first and second branch. The embayment of Cañon City, from which the Arkansas river issues, between Wet mountains and Front

[1] S. F. Emmons, Abstract of Report on Geology and Mining Industry of Leadville, Colorado; Powell, 2nd Ann. Rep. U. S. Geol. Surv. for 1880–1881, pp. 211 et seq.

range, is a second example: several others are known north of Denver, which correspond to the branching off of subordinate parts of the Front range.—

This part of the Rocky mountains is continued to the north-west in the Seminole, Sweetwater, and Wind River mountains until in 43° 30′ N. the Gros Ventre range, also trending to the north-west, approaches the Téton chain, which runs from north to south.

According to Endlich's account these mountains present the following arrangement. A long band of Palaeozoic and Mesozoic strata, compressed in the form of a trough, runs to the north-west; the Archaean mass of the Seminole lies to the north, that of Sweetwater to the south of this band; and since these two larger masses find their continuation in several smaller ones we may fairly suppose that two Archaean branches are at present separated by the sedimentary zone. The much more important Wind River range, which rises in several points to over 13,000 feet (Fremont's peak, 13,790 feet), is a great Archaean chain; its southern part presents an extremely steep slope to the east. This is the continuation of the Sweetwater mountains, and only its eastern flank is accompanied by a sedimentary zone[1].—

The anticlinal of the *Uinta* range, in many parts over 13,000 feet high, is according to the detailed descriptions of Powell very flat and broad on the summit, and terminates on the north in a great master fault, which for certain distances passes into a steep flexure and divides towards the west into two branches. On the south side the subsidence is brought about by numerous fractures and flexures, which follow approximately the same course in a gentle arcuate curve; these we shall have to consider in greater detail[2].

The anticlinal consists chiefly of beds of Carboniferous age, which here attain an imposing thickness; on the northern flank, which is much steeper than the southern, ancient crystalline schist is exposed in one place[3]. The depression of Brown's park, which is let into the northern border and cuts off the O-wi-yu-kuts plateau, appears to have been caused by collapse. Powell estimates the extent of the downthrow on the northern side at 20,000 feet. The southern slope is gentler, and the Yampa plateau joins the range on the south-east as a subordinate anticlinal.

To the east of the great anticlinal of the Uinta two isolated Palaeozoic

[1] F. M. Endlich, Report on the Geology of the Sweetwater District, in Hayden, Geol. Surv. Rep. for 1877, pp. 3-141; O. St. John, Report on the Geology of the Wind River District, op. cit., 1878, I, pp. 175-269; Peale, St. John, and Endlich, Geological Map of Portions of Wyoming, Idaho, and Utah, op. cit.

[2] J. W. Powell, Report on the Geology of the Eastern Portion of the Uinta Mountains, &c.; U. S. Geol. and Geogr. Surv. of the Territ., II Divis., 4to, atlas, 1876.

[3] Zirkel compares it with the Paragonite-schist of the Gotthard; C. King, Rep. 40th Parall., Microsc. Petrogr., VI, 1876, p. 28. According to Wadsworth it is mica-schist: Proc. Boston Soc. Nat. Hist., 1881, XXI, p. 251.

masses arise, Yampa peak and Junction peak; these appear to be segments cut off by transverse faults from a common anticlinal which indicates the continuation of the Uinta towards the Sawatch mountains.

A great flexure, the Midland flexure, with a drop to the south and south-west, runs in an arc from the southern foot of the Uinta and of the forelying Yampa plateau to the prolongation of the Sawatch, and so completes the union with this branch of the Rocky mountains. In this way the Uinta joins in the great virgation, and we are led to the opinion expressed by White that the Uinta and the above-mentioned parts of the Rocky mountains must be regarded as the result of uniform and mutually connected dislocations which possess a common history [1].

The virgation is certainly very different in its nature from any which we have hitherto encountered. In the few cases, as in the Elk mountains, in which lateral movement can be traced at all, it occurs on the concave side and is directed towards the interior, as in the sunken area of the southern Alps. The upturning of the strata, on the edge of the great plain, as a rule simple and confined to a narrow border, presents a much greater resemblance to dragging along a fault, which may in places be overfolded, than to a general tangential movement. The contrast to the great folds of the Appalachians is undeniable and generally recognized. The knowledge we have acquired from observations made in folded chains can therefore hardly be applied here.

In North America various opinions have been expressed as to the formation of the Rocky mountains. They were at first regarded as folded chains. Then they were believed to represent a primaeval coast region, and in support of this the fact was adduced that in different parts of the outer border different sediments come into contact with the Archaean rocks, and that the Palaeozoic series in particular is wanting wholly or in part over long intervals. Finally they were explained as broad 'platforms' which had been respectively elevated between two fractures or two flexures. The last view has been maintained by Dutton, one of the most clear-sighted authorities on mountain structure [2]:

'The width of these platforms varies from 20 to 45 miles. . . . The lifting of these platforms has no significance corresponding to an anticlinal fold. It is expressed by the conception of a block of strata having a fault or equivalent monoclinal flexure upon both sides. . . . In the Uintas we find a repetition of the Park Mountain type upon a grand scale. . . . It consists of a block somewhat broader than Colorado range, but otherwise the type presents no essential modification.'

[1] C. A. White, Report on the Geology of a Part of North-West Colorado; Hayden, Geol. Surv. Rep. for 1876, pp. 3-59, in particular pp. 41, 46, and 51.

[2] C. E. Dutton, Report on the Geology of the High Plateaus of Utah; Powell, U. S. Geogr. Geol. Surv. Rocky Mount., 4to, 1880, atlas, pp. 47 et seq.

It has been believed that these masses or blocks must have been thrust vertically upwards. I shall return to this question later.—

Towards the west the height of the Uinta mountains decreases; the crest of the anticlinal, which in the east lay towards the north, moves towards the middle of the chain; the basset edges of the north and south border gradually join each other in a curve, as though the whole arch were about to flatten out, and where the curved outcrop of the Jurassic formation, approaching from the north and south, would become complete on the summit, a band of trachyte lies transversely across it and conceals its further course. This is the trachyte of the Provo valley[1].—

We now reach a fundamentally different chain, the *Wahsatch*, the western escarpment of which borders the east side of the Great Salt lake and lake Utah.

As regards the structure, three different mountain masses may be distinguished in the Wahsatch: the first forms the northern part of the chain, extending southwards about as far as Salt Lake city; the second is the group of Lone peak, north of lake Utah, together with the heights which follow to the south; the third, different in structure, is that of mount Nebo.

The northern Wahsatch consists of a much disturbed mantle of Palaeozoic strata, which slopes to north-east, east, and south-east; beneath it gneiss and other Archaean rocks appear along the line of fracture for considerable distances. These ancient rocks also form the outlying islands in the Great Salt lake. The second group is distinguished by the granite mass of *Lone peak*, over 11,000 feet high, which is surrounded by Archaean and Palaeozoic strata, and, like the northern Wahsatch, terminates in an escarpment towards the west. The Palaeozoic strata are continued to the south along lake Utah, forming a chain of peaks over 11,000 feet in height: the fault here divides into two parallel branches. To the east of Lone peak another lofty granite mass, Clayton peak, rises out of the Carboniferous strata. Finally, the third part of the Wahsatch, *Mount Nebo*, is an anticlinal, of which, in contrast to the northern Wahsatch and to the group of Lone peak, not the western but the eastern half is broken off and downthrown, so that the steep side faces the east[2].

The granite mass of Lone peak has been the subject of important discussion. It was originally regarded as an eruptive mass, and the rock composing it was described by Zirkel as a recent eruptive granite[3]. The manner, however, in which the several members of the Palaeozoic series abut against the steep granite surface led Clarence King, the leading

[1] S. F. Emmons, Green River Basin, in C. King, Rep. 40th Parall., II, pp. 191, 254; West Uinta Range, pp. 311 et seq., atlas, fol. ii.

[2] An instructive description of the first two groups has been given by C. King, Rep. 40th Parall., Atlas, sheet III, eastern half, and Vol. I, pp. 44 et seq., 154, 745; then Emmons, op. cit., II, pp. 340 et seq., and Howell in Wheeler, Rep. 100th Merid., III, pp. 233 et seq.

[3] F. Zirkel, Microsc. Petrogr.; C. King, Rep. 40th Parall., VI, pp. 50, 58.

investigator of these mountains, to regard this granite mass as the remains of an extremely ancient pre-Palaeozoic continent or island, and this view has influenced all later conceptions of the formation of this lofty range. According to Geikie, who has visited the spot, Lone peak must really be regarded as an eruptive mass of more recent age, certainly post-Carboniferous—a view also adopted by Whitney[1]. Geikie points to the absence of granitic fragments or pebbles in the sediments alleged to be deposited over it, and above all to the conversion of the limestone into white marble and the numerous dykes of granitic porphyry which appear in the neighbourhood of the granite. The aureole of ore deposits of precious metals which surrounds the second granite mass, Clayton peak, certainly supports this latter view, and Professor Reyer informs me that in this region he has met with vesuvian in the zone of contact: Lone peak and Clayton peak, on the Salt lake, would thus appear to be homologous with the Adamello or Predazzo.—

The northern part of the Wahsatch mountains is followed to the north-east first by a broad Palaeozoic synclinal, which forms Cache valley, then by a closely crowded series of Mesozoic chains (only very inadequately represented on Pl. VI), which extend as far as the Téton mountains. These remarkable ranges have been described by St. John and by Peale[2]. They are folded ranges, indeed true anticlinals and synclinals, traversed by several longitudinal fractures. Each of these folds runs at first meridionally from south to north, bends to the north-west, and then disappears beneath the broad basaltic sheet of Snake river. These sedimentary folded ranges thus describe precisely the same kind of curve as the great branches of the Rocky mountains in their virgation, and the most northerly of them, Snake River range, joins south of the Tétons the south-west side of Gros Ventre range, which, as we have seen before, is connected with Wind River range.

In the Caribou range running to the north-west, which immediately follows the Snake River range on the south-west, an overfold actually appears, such as is usually produced by tangential movement; as in the Elk mountains, the structure of which is otherwise so different, the movement is directed to the south-west.

*Colorado plateau and the High plateaux of Utah.* The Colorado plateau is bounded on the east by the Rocky mountains, on the north by the Uinta; to the west it is immediately followed by the remarkable fractured table-land of Utah, with its network of faults which have already

[1] A. Geikie, On the Archaean Rocks of the Wahsatch, Am. Journ. Sc., 1880, XIX, pp. 363-367; J. D. Whitney and M. E. Wadsworth, The Azoic System and its proposed Subdivisions, Bull. Mus. Comp. Zool., Cambridge, 1884, VII, pp. 499-511.

[2] O. St. John, Report on the Geological Field-Work of the Teton-Division, in Hayden, Geol. Surv. Rep. for 1877, pp. 323 et seq. (lat. 43°-44° 15′ N., long. 109°-112° 15′ W.); A. C. Peale, Report on the Geology of the Green River District, op. cit., pp. 509 et seq. (lat. 41° 45′-43° N., long. 109° 30′-112° W.); Geol. map in Rep. for 1878, I.

been described. This table-land is bounded on the west by great faults: on the Hurricane fault (p. 130, Fig. 13) the dislocation above the Virgen river amounts, according to Dutton, to at least 12,000 feet; to the south the extent of the throw diminishes; but on the west it is replaced by the Grand Wash fault, which crosses the Colorado river at the mouth of the Grand cañon, and there presents a throw of over 5,000 feet.

The cliff of this fault facing west turns south of the Colorado to the south-west towards the Aubrey cliffs. Further on we may regard the southern boundary of the region we are about to discuss as formed by those extensive lava fields, which from the range of Mimbres to the Mogollôn mountains occupy the border region between Arizona and New Mexico; they send off one branch to the north-north-east, to Mount Taylor beyond Fort Wingate, and a second to the north-west which proceeds far beyond the Mogollons and the volcanic group of San Francisco (13,000 feet in height), towards the end of the Grand cañon.

In this region the waters of the Colorado unite, and the river sinks its bed more and more deeply into the nearly horizontal beds of a series which is for the most part Carboniferous, until, to the south of the Kaibab, about 6,000 feet below the surface of the plateau, it flows through the grandest erosion valley of the world. The Grand cañon terminates on the Grand Wash fault, and the country beyond it lies several thousand feet lower.

The explorations of Marcou, Newberry, Powell, and above all the admirable investigations of Gilbert, have made this country familiar to us; for the High plateaux of the west and the Grand cañon we have besides the two comprehensive monographs with which Dutton has enriched geological literature [1].

The table-land of Colorado and the adjacent highlands of Utah are distinguished by excessive dryness; over wide areas every trace of a humus layer is absent, and only the most impoverished vegetation occurs or next to none at all. We are here afforded a deeper insight into the structure of the land than in almost any other part of the earth's crust. At the bottom of the Grand cañon, sharply inclined Archaean rocks and Silurian beds are exposed to view; they have been worn down by abrasion to a uniform plain which can be traced for many miles; upon this eroded surface there rest in transgression the thick deposits of the Carboniferous period lying horizontally, and thence upwards all the succeeding sediments follow one another conformably as far as the

[1] G. K. Gilbert, The Colorado Plateau Province as a Field for Geological Study, Am. Journ. Sc., 1876, 3rd ser., XII, pp. 16–24 and 85–103, and in particular the accounts of Gilbert, Marvine, and Howell, in Wheeler, Geogr. Surv. 100th Merid., 1875, III; further, C. E. Dutton, Report on the Geology of the High Plateaus of Utah, Powell, U. S. Geogr. Geol. Surv., Rocky Mountain Region, 4to, 1880, and Tertiary History of the Grand Cañon District, op. cit., 4to, 1882, atlas.

lacustrine deposits of the Tertiary period. Gaps there are in the series certainly, but above the base of the Carboniferous no discordance in the lie of the beds again occurs. The series resembles in all essential respects that which we have already met with in the west. The Cretaceous deposits extend from the High plateaux of Utah, past the Moquis Pueblos and Port Defiance, towards Texas, and Dutton even suspects that between latitudes 34° and 37° N. they extend across the continent from the Atlantic to the Pacific Ocean.—

Bearing in mind what has been said above with regard to the opinions of the most distinguished American geologists on the formation of the Rocky mountains, I will next attempt to compare the views held regarding the structure of this most instructive region with those which have arisen in Europe as a result of the investigation of those mountains which in my opinion show the greatest structural resemblance to the chief parts of the Colorado plateau and its bordering masses.

For this purpose we will retrace our steps to the north and north-east, and return to the structure of the Uinta mountains.

The arch of the Uinta rises to a height of 10,000 to 11,000 feet, in its highest point to 13,694 feet. It is cut through by the Green river. Where the river enters the mountains from the north, the foot of the slope lies at a level of not quite 6,000 feet; where it leaves the mountains the level is somewhat over 5,000 feet. The arch consists of Carboniferous beds; but if we could produce from north and south the upturned beds which crop out at its foot over the summit, they would attain an altitude, according to Powell's estimate, of about 30,000 feet. Nevertheless, as Powell expressly declares, several important dislocations, such as those on the Yampa plateau and in Brown's park, are true subsidences [1].

The decisive question, however, is whether these mountains have been elevated, or the surrounding country depressed.

Let us first consider White's account of the relations between the Uinta and the Rocky mountains [2].

Between the Uinta and the end of the Sawatch range rise as connecting links the two Palaeozoic masses of Junction peak and Yampa peak. The eastern extremity of the Uinta is surrounded by a rampart of upturned basset edges, but at a trifling distance the strata again become horizontal; a second rampart of the same kind surrounds Junction peak, and a third Yampa peak. These mountain masses are, like the Uinta, of Carboniferous age; their upturned borders are Mesozoic. Junction peak is

[1] Powell, Geology of the Uinta Mountains, pp. 176, 203, 208.

[2] C. A. White, Report on the Geology of a Portion of North-West Colorado, in Hayden, Geol. Surv. Rep. for 1876, pp. 5-60, in particular pp. 40-51. In a note, p. 41, he says: 'By making use of the expressions *uplift* and *upthrust* I do not intend to express any opinion as to the actual movement in the dislocation of the strata, whether it was upwards or downwards.'

nearly 20 kilometers long, and 6·5 kilometers broad; the extent of the dislocation from summit to base is estimated at 8,000 feet; Yampa peak is somewhat smaller, the dislocation possibly greater. White compares them with iron bolts which are hammered through sheet iron and draw up the edges, without, however, intending by this to express a definite opinion as to whether the dislocation took place from below upwards, or in the opposite direction.

To the south of these mountains, several dislocations run in a direction which indicates the connexion between the Uinta and the Sawatch range; the most important is the great Midland flexure, already mentioned above; it is this which surrounds the southern border of the great Uinta plateau, sweeps round the Yampa plateau, which follows on the south, and then crosses the White river in a vast unbroken curve; continues under the name of the Great Hogback flexure along the west side of the foot-hills of the Sawatch, and finally reaches the reversed south-west side of the great overfold of the Elk mountains (p. 164, Fig. 22).

This flexure, which in its course from the south border of the Uinta to the Elk mountains measures over 300 kilometers, thus embraces within its great arc the whole north-east part of the Colorado plateau; its beds dip to the south, south-west, or west, i. e. from the mountains towards the lower lying land, and it is accompanied for almost its entire length by hogbacks, i. e. by long ridges formed by the outcrop of steeply inclined beds.

After what has been said above (p. 124 et seq.) with regard to the movements of the outer crust of our planet, I cannot consistently regard this flexure as anything else than an indication of the subsidence of the whole vast region which lies to the south, south-west, and west. The inversion of the Elk mountains must then be classed with those cases of overthrust in which the movement has been directed towards the subsidence, and of which we have given several examples in Europe. The circumvallate outcrops of upturned beds, which in closed curves surround on all sides Junction peak, Yampa peak, and each of the other great mountain masses, do not admit moreover of any other explanation; these also represent borders of flexure. The mountains themselves must then be classed with the horsts of Europe, the Schwarzwald, Morvan, and the Cima d'Asta. The hogbacks with their upturned beds are thus only the result of flexure along the fault, and I should not hesitate to compare the long Midland flexure with a peripheral line, in the sense in which this term has been already defined. Instead of White's comparison of the bolt which is driven through sheet iron I would propose another. A stake is driven in at the edge of a pond, so that its upper end stands just below the level of the water. The water becomes covered by a sheet of ice; the level of the water falls; the covering of ice gives way and the stake is exposed to view. Great plains may sink; as soon as their foundation gives way they

follow the force of gravity. But we know of no force by which isolated mountain masses could be elevated side by side and independent of each other.

As a consequence of this explanation it follows that the whole country once stood 30,000 feet above the existing sea-level; a result which may well occasion surprise, but without invalidating the argument. If we were to pile upon the European horsts the succession of strata which once covered them, if, for instance, we could extend the sedimentary series of the southern Alps on to the Cima d' Asta, we should obtain figures equally extraordinary.

In concluding our consideration of this region I will add the following acute observations by Emmons, which are of great importance in the interpretation of certain peculiarities in the behaviour of the river courses [1].

The Green river leaves the Tertiary land in the north to enter the mass of the Uinta at right angles, and follows a tortuous course along a channel which is excavated in the midst of hard quartzite to a depth sometimes of 3,000 feet. After traversing the Red cañon the river reaches the plain in the sunken area of Brown's park; it does not flow through this region, however, but again enters the mountains and crosses the south part of the Uinta in the cañon of Lodore. Emmons has shown that the shore lines of the later Tertiary lakes may be traced on the north side of the Uinta to a height of 10,000 feet. Just as the Uinta is cut through by the Green river, so is the isolated Junction peak by the Yampa, which traverses it in a deep cañon, and the same river also intersects the northern part of Yampa peak. It will at once become apparent why the rivers do not prefer the Tertiary plains. Horizontal strata of Tertiary age also lie on Yampa peak. The course of the Green river across the Uinta was already marked out at the time when the Tertiary lakes stood at their highest level, and the river must once have flowed at a height of more than 9,000 feet above the sea; it is also clear, says Emmons, that the course of the river across Junction peak and Yampa peak was chosen at a time when these hard rocky masses still lay buried beneath the Tertiary strata.—

Now at last we descend from the foot-hills of the Uinta to the lower country and find it surrounded by a long series of continuous walls. Each of the principal groups of the stratified rocks becomes horizontal at no great distance from the flexures, and so extends towards the lower country to terminate in a long wall-like cliff. These cliffs have not been produced by fracture, but by a particular kind of erosion. The outcropping edges are attacked and destroyed; they retire further and further away, and thus a great terraced country arises, characterized by long continuous wall-like steps, resembling those of the eastern Sahara. The lowest strata crop out

[1] S. F. Emmons; The Green River Basin; in C. King, Report Geol. Exploration of the 40th Parall., II, 1877, p. 197.

near the Colorado. Dutton estimates the average thickness of rock which has been destroyed and carried away at 10,000 feet.

From this plain there rise in the south the laccolite mountains of the Sierra San Miguel, Sierra Carriso, Sierra Abajo, and, further to the west, the Henry mountains (p. 149); but if we approach the western edge of this low-lying region we shall meet first an oval abraded dome, not wholly unlike that of the Black mountains of Dakota, situated in front of the Rocky mountains, but on a smaller scale. It lies on the Waterpocket flexure, the first flexure leading to the more elevated country (15, Fig. 13, p. 130).

The flexure marks the commencement of the High plateaux of Utah, the southern part of which is traversed by the Grand cañon. The geologists who have explored this country describe it as a land of wonders, such is the unparalleled magnificence of the scenery, the clearness and simplicity of the structure, and the variety of colour in the rocks, which produce a landscape with most unusual effects; certain it is in any case that there are not many regions of which we possess such masterly descriptions. It is precisely the excellence of these accounts, which bring the simple features of its structure so plainly before the eye, which must be my excuse if, though I have not myself visited the country, I venture to draw other conclusions from them than those set forth in the accounts themselves. In his latest works Dutton, like most of his predecessors, explains the isolated blocks between the faults, the horst of the Kaibab for example (between 6 and 7, 8, Fig. 13), as *elevated*. I consider, on the contrary, that the present condition is the result of unequal subsidence.

The manner in which these great lines of dislocation proceed from the Wahsatch mountains and Mount Nebo has already been described (p. 129): Dutton emphasizes the fact that all the lines are more or less convex towards the west; that many circumstances, particularly the nature of certain Mesozoic sediments, point to the existence of a Mesozoic continent in the west, on the site of the existing Basin ranges in the west of Utah and parts of Nevada; and that the lines of disturbance correspond on the whole to the border of this continent. At the same time, however, their course is so clearly concordant with that of the Midland and Great Hogback flexure at the foot of the Uinta and the Rocky mountains, that we may fairly regard the whole of these flexures which surround the Colorado plateau, from the Grand cañon as far as the Elk mountains, as a system of peripheral lines of dislocation, in the same sense as we have spoken of a peripheral line in the case of the Tyrrhenian sea. The horsts, such as the Kaibab, may possibly be wedges caught between two faults.

As regards the manner in which the several plateaux and fractures are related to one another, I must refer the reader to the discussion of this subject in Part I; it has already been observed that the Hurricane fault

(2, Fig. 13) produces a great downthrow on the Virgen river, which diminishes towards the south as it approaches the Grand cañon, while correspondingly the throw of the Grand Wash fault (1, Fig. 13) increases—a phenomenon frequently observed by Mojsisovics in the subsidence faults of the southern Alps. A zone of smaller fragments of the plateau lying between two principal fractures, an instance of fragmentation in a fault trough, has been represented on p. 132, Fig. 14.

The faults are not all of the same age; some of them have experienced different movements at different times. The East Kaibab fault, according to Dutton's data, is probably one of the oldest.

The observations made on the manner in which the fault of the Toroweap (3, Fig. 13) crosses the Grand cañon are very instructive.

In this region the Grand cañon consists of two stages. The upper ravine, 8 to 9 kilometers broad, is bounded by cliffs about 2,000 feet high; at their foot lies a plain named by Dutton the 'Esplanade,' and in this the second ravine, the inner cañon, is excavated; this is 3,000 feet deep, and from edge to edge only 3,500 to 4,000 feet broad. On the top of the table-land cut through by the Grand cañon, numerous basaltic eruptions may be seen; ancient lava sheets are present, and considerably over a hundred much younger ash cones, both great and small. These cones, however, occur not only on the table-land, but in isolated cases also within the cañon on the esplanade, and here and there the black scoriaceous mass of a recent basaltic flow has tumbled over the battlements of the great rocky walls into the inner abyss [1].

The eruptive cones stand on the Palaeozoic 'plates,' arranged according to no recognizable law in longer or shorter rows; their occurrence on one of the great lines of dislocation is a rare exception. A case of this kind is furnished by the ash cone, 580 feet high, named by Dutton 'Vulcan's throne'; it stands on the edge of the esplanade towards the inner cañon just at the point where the dislocation of the Toroweap cuts across it. The throw of the Toroweap is towards the west, and amounts to 600 to 700 feet; the great ravine suddenly loses an equal amount in depth, a consequence of the fact that the whole surrounding country is equally diminished in height. Of the dislocation Dutton says, 'All looks as clean and sharp as if it had been cut with a thin saw and the smooth faces pressed neatly together [2].' With equal sharpness it cuts through a number of basaltic flows on the esplanade. The sequence of events is unmistakable. So nature writes her own chronology, and we may well envy the observers who are called upon to read this history in the original.

[1] Dutton, Tertiary History of the Grand Cañon District, pl. xix. In one case streams of this kind caused the Colorado to rise 400 feet, until it had again forced a way for itself: op. cit., p. 95.

[2] Dutton, op. cit., p. 93.

The manner, however, in which the basalts have ascended in the narrow fissures, often exposed to a great height in the cañon and without cooling along the walls, have piled up their ash cones, and poured out their lavas far above, can hardly be compared with what happens in the normal eruptions of Aetna or the Lipari isles. It rather recalls the injection of a great anatomical preparation, and suggests the opinion already more than once expressed in the presence of such phenomena, that the subsidence of great mountain segments in itself produces an injection of this kind, or at least greatly facilitates it [1].

This, however, presupposes that the great orographic blocks have really subsided, not that the horsts have been elevated by an unknown force. That the dislocations have as a whole been regarded by the observers as elevations is explained in this case by further deductions. Kaibab plateau, composed of Carboniferous deposits, attains a height above the sea of 9,300 feet; the whole thickness of the Mesozoic, and perhaps too of the oldest part of the Tertiary formation piled upon it, gives figures not much smaller than those which Powell obtained from his imaginary restoration of the Uinta mountains. Then, or so at least it appears, we lose all means of forming an opinion as to the state of things on the south and east, and the level of the water will stand high over all the existing mountains. We shall return to questions of this kind later, when I hope to be able to show that many generally accepted views as to the position of the sea-level in past epochs of the earth's history require revision; in the present case, however, we may observe that several assumptions are permissible—for example, the conception of a vault of great amplitude, brought about by tangential stress detached from its base so as to leave a very wide cavity, which fills with lava thus relieved from pressure, a *macula* to use Dutton's expression (p. 175); the roof of this then collapses, and the various fragments subside to different depths. It is impossible, in any case, to ignore two facts: the first, that in other regions large masses have subsided along similar fractures and flexures solely under the influence of gravity; and the second, that no force of any kind is known which would be capable of pushing up, singly and between smooth surfaces, a number of mountain blocks, great or small, and of maintaining them persistently in position, in opposition to the force of gravity.

[1] F. Posepny, Geologisch-montanistische Studie der Erzlagerstätten von Rézbánja, published by the Ungar. geol. Gesellsch., 8vo, 1874, p. 190: 'How could one otherwise explain the presence of comparatively thin but long dykes of greenstone which penetrate every fissure of the rock and include thin pointed fragments, except by the supposition that the soft mass of rock was pressed into the already existing fissures by the weight of rock resting upon it? Each of the ore-bearing districts . . . has its large mass of eruptive rocks . . . which have been pressed out during the subsidence, and indicate, so to speak, the extent of the subsidence.' Also Dutton, Geology of the High Plateaus, p. 130:

*Basin ranges.* This region is very different from the preceding. It is bounded on the east, along the Great Salt lake, by the fault of the Wahsatch, and on the west by the east flank of the Sierra Nevada, and measures 600 to 700 kilometers in breadth. Numerous comparatively short mountain ranges, more or less meridional in direction, rise in remarkable isolation out of its desert plains. Their slopes are buried up to a great height under their own débris; a consequence of the absence, in a great part of this region, of outflow to the sea. Between these chains extends salt desert or barren steppe. Its exploration is a brilliant testimony to the devotion and endurance of our colleagues in America.

The south part of the Basin ranges consists, so far as we are acquainted with it, of Archaean rocks and Palaeozoic strata poor in fossils. In the north, where its direction is nearly meridional, the range is much more diversified; I follow here the descriptions by Clarence King, Hague, and Emmons [1].

'The geological province of the Great Basin,' writes King, '. . . has suffered two different types of dynamic action: one, in which the chief factor evidently was tangential compression which resulted in contraction and plication, presumably in post-Jurassic time: the other of strictly vertical action, presumably within the Tertiary, in which there are few evidences or traces of tangential compression [2].'

Hitherto we have seen in the region of Colorado the collapsing tableland; now we reach the collapsed folded ranges. We have, however, already encountered a troop of true folded ranges extending from the Wahsatch range past Bear lake towards the Tétons; these were found to disappear beneath the basalt flows of the Snake river; the Wahsatch itself presents an unmistakable resemblance to the chains which we are now about to discuss. In the Great Basin the folding force manifested itself with particular intensity on the west side of the region, where, as we shall see directly, it has determined the form of the entire Sierra Nevada. Some of these folded ranges, which may even still be followed for more than 150 kilometers, were originally convex towards the west. The faults by which the folds are traversed strike in different directions, but the majority would appear to run nearly north and south; they cut the folds at all kinds of angles. Such is the origin of those abrupt and isolated fragments of chains, which trending more or less with the meridian at present occupy this broad space; the course of the sharply broken off edges would be still more striking if it were not for great masses of

'A close examination of the details of volcanic discharges leaves an impression that they are pressed forth by the weight of the rocks covering their reservoirs, and that their emergence is only a hydrostatic problem of the simplest kind.'

[1] C. King, U. S. Geol. Exploration of the 40th Parallel, I, p. 742 et passim, and the accounts of Hague and Emmons, op. cit., II, pp. 469 et seq.

[2] C. King, op. cit., I, p. 744.

eruptive rocks, chiefly rhyolite, which confuse and conceal the orographic purity of their form. On closer observation we may recognize in one of these ranges the fragment of an anticlinal, in another a monoclinal ridge flanked with great volcanic flows, in others again two anticlinals with the intervening synclinal obliquely cut across, and so on; we have indeed before us a mighty folded range, thoroughly hewn up, broken into pieces and foundering into the depths. In certain cases horizontal displacements have taken place along the fractures; in West Humboldt range, for example, the anticlinal is cut through by a transverse fracture, and the southern half is heaved about 8 kilometers towards the south-east [1]. The two great principal faults which bound the Basin ranges on the east and west are regarded as 'lines of weakness' along which repeated movements have taken place; against each of these lines a great inland lake accumulated at a quite recent period—at the west foot of the Wahsatch range, lake Bonneville of Gilbert, and at the east foot of the Sierra Nevada, lake Lahontan of King; the last remnants of these lakes are the Great Salt lake, Utah lake, and Sevier lake in the east, and the sheets of water between Pyramid, Carson, and Walker lake in the west. The terraces left by the subsiding water encircle in regular lines the slopes of the broken chains, which rose as elongated islands out of the two lakes in much the same way as Antilope and Stansbury islands now rise from the existing waters of the Great Salt lake.

A thousand feet above the present level of the Great Salt lake lies, according to Gilbert, the highest shore line of lake Bonneville; a second, very clearly marked, occurs at a level of 600 feet, the Provo beach; lines of less importance lie between and below these; the waters of the lake flowed out to the north through Cache valley, and the sharply cut terrace of the Provo line corresponds to the level of a reef of rock crossing the line of discharge, which withstood the erosion of the stream for a longer time than the less resistant rocks above it. At the bottom of the ancient lake stand ash cones of basaltic tuff, some engirdled by the ancient terraces of the lake, some of more recent age than these terraces. Gilbert has shown that the strand-lines are at present neither parallel to one another nor horizontal. They lie lowest on the fault of the Wahsatch, and then rise considerably towards the middle of the lake, on the north side reaching a height of about 100 feet, and on the south even more. These highest points lie in the north on the meridian of 113°, in the south between long. 113° and 114° W. [2]

[1] Hague, op. cit., II, p. 736. Here the question would certainly be permissible, whether it might not be a matter of a dislocation produced during the folding, such as is by no means uncommon in Europe.

[2] G. K. Gilbert, Contributions to the History of Lake Bonneville; Powell, II, Ann. Rep. U. S. Geol. Surv. for 1880–1881, pp. 167–200, with maps of the deformation of the lake. In addition to the inclination of the terraces Gilbert also describes an evidently recent

Further to the west we possess only a single measurement of the height, and this indicates a descent; when these instructive researches are extended towards the west we shall learn whether a new anticlinal is being formed in the axis of the ancient lake between the meridians of 113° and 114°, or whether the western side of the fault of the Wahsatch is continuing to subside.—

The distribution of the sediments within the Basin ranges is scarcely less remarkable than the structure of these mountains. The last marine deposit of the eastern mountains, the Cretaceous formation, does not pass beyond the fault-line of the Wahsatch in this latitude. The same may almost be said of the lower Mesozoic deposits, the equivalents of the Jurassic and Trias; they are not represented beyond this line for a long distance except by a few fragmentary remains. The Palaeozoic series, of such trifling thickness on the eastern border of the Rocky mountains, but swollen out through the Uinta to the Wahsatch to many thousands of feet, forms, together with Archaean rocks and recent lavas, the whole of the eastern half of the Basin ranges. Beyond the meridian of 117° the composition of the mountains completely changes. In the ranges of Toyabe and Shoshone and in the Battle mountains, not far from 117° 15′, the maps show outcrops of the upper Carboniferous in proximity to granite and Archaean rocks, rising singly from the plain or surrounded by rhyolitic flows. Already in the next chains to the west, in the Desatoya and Havallah range, the succession is again entirely different; the whole Palaeozoic series has disappeared, and immediately upon the granite lie thick deposits containing Arcestes, Trachyceras, Cassianella, Daonella, and other forms characteristic of the marine development of the Trias as it occurs in the eastern Alps. Thus an important line of demarcation in the distribution of the formations lies somewhat to the west of the centre of the Basin ranges; westwards from 117° 15′ to the Pacific Ocean, deposits of the Palaeozoic period are unknown, with the exception of a band of Carboniferous limestone in the northern part of the Sierra Nevada[1].

The boundary of the Palaeozoic deposits in the Basin ranges runs from

'fault-scarp' close to the west foot of the Wahsatch; it is 30 to 40 feet high, and is regarded by Gilbert as a proof that the Wahsatch is rising; this assumption is hard to reconcile with the inclination of the terraces. The fault-scarp may also have arisen through the subsidence of the west wing. These are questions the solution of which may be hoped for from the further prosecution of these researches. Gilbert, A Theory of the Earthquakes of the Great Basin; Am. Journ. Sc., 1884, XXVII, pp. 49–53.

[1] Gabb has described a number of remarkable fossils from Volcano, south-east of Walker Lake, Nev., from the western part of the Basin ranges, which partly belong to the Trias with *Arc. Ausseeanus* and *Cassianella lingulata*, partly to a higher stage which Gabb includes in the Lias. *Arietites Nevadanus* does indeed strongly recall the European Lias; Gabb even places all the slates of the Sierra hitherto assigned to the Jurassic in the Lias. Gabb, Description of some Secondary Fossils from the Pacific States; Am. Journ. of Conchol., 1870, V, pp. 5–18, pl. iii–vii.

the above-mentioned outcrops in the Battle mountain, Toyabe and Shoshone ranges towards the south, with a slight deviation to the west, so that south of Owen's lake it approaches the border of the Sierra Nevada, and there the whole breadth of the Basin ranges lies within the Palaeozoic region.

The Trias formation and a series of Jurassic limestones and slates which accompany it attain their greatest development in the Havallah, Pah-Ute, and West Humboldt chains; in the Eugene mountains and Montezuma range the Jurassic deposits again acquire great importance; then follows, from the meridian of about 119°, a region almost exclusively granitic, with a development of Jurassic slates, until, in the Sierra Nevada, the structure of the Havallah range and of similar chains is repeated.—

Before proceeding to the description of the Sierra Nevada, a few observations may be added as to the manner in which the Basin ranges are continued towards Mexico.

The nature of these prolongations differs in many respects from that of the ranges themselves. The Carboniferous limestone appears in imposing thickness along the Sierra Madre. Beds of quartzite and conglomerate occur, which Rémond regards as representative of the Trias; these contain coal and a flora rich in ferns, recalling in many of its characters that discovered by Newberry beneath Cretaceous beds on the Colorado plateau, near the Moquis Pueblos. The occurrence of Jurassic is doubtful. On the other hand, the Cretaceous deposits of Texas with *Ammonites pedernalis* and many other characteristic species extend as far as Arivechi, on the west side of the Sierra Madre. The comparatively recent eruptive rocks found between the chains and beside them, appear to possess a similar significance in Sonora as in the United States[1].

Those chains in western Texas which extend further to the east between the Rio Grande and Rio Pecos, such as the Sierras Los Organos Hueco, S. Sacramenti, and Guadelupe, must be regarded as the continuation of ridges which, like the Zuni range, rise in the south of Colorado, and of those which have already been mentioned to the south of Galisteo. They have been investigated by Jenney, and shown to consist of Palaeozoic deposits which rest on granite; the Cenomanian beds of the Llano Estacado are also visible here along the Rio Grande[2].

[1] A. Rémond, Notice of Geological Explorations in Northern Mexico (prepared for publication by J. D. Whitney), Proc. Calif. Acad. Nat. Sc., 1866, III, pp. 243-257; W. Gabb, Notes on some Mexican Cretaceous Fossils, Geol. Surv. of California, Palaeontology, II, 1869, pp. 257-276; by the same, Notice of a Collection of Cretaceous Fossils from Chihuahua, Mex., Proc. Acad. Nat. Sc., Philadelphia, 1872, pp. 263-265. Gabb also describes Cretaceous fossils, such as *Amm. Guadeloupae*, *Exog. costata*, and others, collected by Kimball at Nugal, Chih., in the region of the silver mines.

[2] W. P. Jenney, Notes on the Geology of West Texas near the 32nd Parallel; Am. Journ. Sc., 1874, 3 ser., VII, pp. 25-28. The Llano Estacado here exhibits red sandstone

Towards the east there now follows the vast region of central Texas; its horizontally stratified Cretaceous and Palaeozoic beds were long ago made known to us by F. Roemer[1].

*Sierra Nevada.* The Sierra Nevada is a mighty mountain mass extending continuously through more than six degrees of latitude in a direction from north-north-west to south-south-east: in twenty peaks it rises to over 14,000 feet. Towards the east it descends in a steep slope to the desert region without outflow, which marks the limit of the Basin ranges; but although this descent amounts to more than 6,000 feet, yet on account of the height of the socle, on which the Basin ranges stand, it is by no means so great as that of the western slope, which descends by the valleys of the Sacramento and Joaquin (that is in its middle region) to a trifling height above the sea. The exploration of this great range redounds to the lasting honour of Whitney[2].

On the south the chain is lofty and less broad, very steep towards the east, and formed almost entirely of granite: Jurassic slates form a narrow belt on the western side. Further to the north, beyond lake Mono, great masses of volcanic rock appear on the east side: the boundary between these and the neighbouring Basin ranges, which are also granitic in this locality, is thus less striking: further to the north it again becomes more clearly marked. The line which thus cuts off on the east this great fragment of the earth's crust marks a gigantic fault.

The Jurassic slates on the west side increase rapidly in breadth to the north, or towards the boundary of Mariposa, and finally on the north of the America river they form almost the whole slope, the granite being exposed only in isolated masses; towards Pyramid lake they even extend over to the east side. At one locality in the north, Genesee valley, Plumas, these slates are accompanied by Alpine Trias, and in several places by a zone of Carboniferous limestone; they finally disappear beneath the broad sheets of recent lavas which cover the most northerly part of California, as well as a large region in the south of Oregon and beyond it.

These Jurassic slates are very poor in fossils; they contain intercalations of diabase tuff, and include, in association with serpentine, the gold-

which is believed to be Triassic, some brown sandstone possibly Cretaceous, and then the beds with *Exogyra Texana*, *Caprina crassifibra*, and *Ammonites pedernalis*; finally, hard limestone about 30 feet thick.

[1] F. Roemer, Die Kreidebildungen von Texas und ihre organischen Einschlüsse, 4to, Bonn, 1852.

[2] J. D. Whitney, Geological Survey of California, Geology, I, 1865; I follow in particular the last description by Whitney in The Auriferous Gravels of the Sierra Nevada of Calif., Mem. Mus. Comp. Zool., Cambridge, VI, 1879-1880, pp. 27-52, 505 et seq. For all the details of the occurrence of coal, quicksilver, and petroleum, see the accounts of Goodyear and Peckham in Whitney, Geological Survey of California, II, 1882, The Coast Ranges, Append. Further, J. Leconte, On the Evidence of Horizontal Crushing in the Formation of the Coast Range of California; Am. Journ. Sc., 1876, 3 ser., XI, pp. 297-304.

bearing quartz dyke, 120 kilometers in length, which is known by the name of the Mother lode. These are the chief gold-bearing rocks of California. They are steeply upturned and almost always inclined to the north-east, exclusively so in the south; the dip is therefore reversed.

In the 'foot-hills' on the west of the Sierra, a second zone of granite makes its appearance, and here the chain is bordered along its whole length, except where interruptions occur due to denudation, by a long belt of horizontal marine beds, which belong to the Cretaceous and Miocene periods. Although the Cretaceous deposits which extend from the north towards this region are only known as far as Folson, yet it follows from this that the chief disturbance of the Jurassic slates, to which they owe their dip, is probably of pre-Cenomanian age. Beds representing the Neocomian and Gault are not known in the foot-hills.

The elements which compose the Sierra Nevada are thus the same as those which are met with in the Basin range near the meridian of 117°. We may thus include this lofty Sierra among the Basin ranges, and regard it as the outer border of the whole structure.

The vast size of this orographic segment, the high dip of the slates to the north-east into the interior of the mountains, the fact that the granite appears not only at the foot and on the crest of the chain, but also in isolated masses within the slates, are all very remarkable facts, and we can readily understand the reserve with which Whitney, even after his long-continued and earnest investigations, expresses himself on the formation of the Sierra, only indicating in explanation of the great thickness of the slate that it has probably been folded back upon itself [1].

These features recall the northern border of the Finster-Aarhorn mass. The inversion of a thick stratified complex along the outer border of great mountain segments is a phenomenon widely distributed in the Alps. In west America it appears to occur far more rarely, and this may be connected with the fact that extensive overthrusting in this region appears to be restricted to a few isolated zones. Among all the mountain ranges of western America, the western slope of the Sierra Nevada appears to me to present, apart from the horizontal deposits at its western foot, the greatest resemblance to Alpine structure, particularly to the outer side of the Swiss Alps.

The broken chains of the Basin ranges show convexity to the west; I regard the Sierra Nevada as having been overfolded in the same direction.

The steep eastern slope was the scene of the earthquake of March 26, 1872, on which day, according to Whitney, the shock occurred simultaneously over the whole distance between the latitude of 34° and 38° (p. 74).

[1] Whitney, loc. cit., in particular Auriferous Gravels, p. 506.

*The Coast ranges.* To the west of the longitudinal valley of California rise the *Coast ranges*, which in many places attain a height of 5,000 feet, and often present steep declivities towards the Pacific Ocean. In the study of this group Whitney is again our guide [1].

The Coast ranges present no continuous crest, or principal chain. A number of separate chains with a common general direction and composed of similar rocks run beside one another and replace each other, to some extent recalling the chains of the Swiss Jura. Their structure, however, is less regular than that of the Jura, and may be described as the result rather of crumpling than folding. Anticlinal chains alternate with monoclinal ridges and merge one into another. In the south these independent chains are especially numerous, and they have received many names which date from the time of the Spanish mission, e.g. Sierra de Santa Monica, de Santa Inez, de San Rafael, and others.

The northern spurs of the Sierra de la Santa Cruz close the large and remarkable bay of San Francisco, while towards the interior the group of Monte Diabolo separates this bay from the principal valley of San Joaquin. Further to the north, nearly as far as the river Klamath, the structure is more uniform and the special names disappear. In the whole region of the Coast ranges no member of an older Mesozoic or Palaeozoic deposit is known, with the exception of a bed containing Aucella, which in all likelihood belongs to the upper Jurassic.

In the south, in the neighbourhood of Los Angeles, on the sea-shore near Santa Barbara as far as Punta Concepcion, and in many other places in the interior of the mountains, finely banded, much folded shale, apparently of middle Tertiary age, occurs, which contains large quantities of asphalt and petroleum. It is covered by Miocene sandstone, which has likewise shared in the movements of the mountains.

Beneath the bituminous shale no representative of the Eocene period is known to occur: the next oldest deposits belong to the Cretaceous system. Beneath this, but in places, as it would appear, immediately beneath the Tertiary beds, granite, hornblende schist, and metamorphic schists appear: these rocks form the highest parts of the chains.

Some observers seem to incline to the view that these rocks, and particularly the granite which forms the basement of the southern part of the Coast ranges, are the same as those of the Sierra Nevada, on the other side of the Téjon pass; Whitney, on the other hand, disputes this identification and strongly advocates the Tertiary age of the granite of the Coast ranges [2]: some go so far indeed as to assign some of the mica-schists to the Miocene period. There is a general agreement that the Cretaceous

[1] Whitney, Geology of California, I, pp. 1–197, and Auriferous Gravels, pp. 15–26.

[2] Whitney and Wadsworth, The Azoic System; Bull. Mus. Comp. Zool., Cambridge, 1884, VII, p. 550 et passim.

which lies beneath the bituminous shales has suffered considerable alteration, and that the numerous bands of serpentine of the Coast ranges are included in it. Beds of impure red and green jasper, accompanied by impure serpentine and hard unfossiliferous sandstone, are particularly characteristic of these parts of the Cretaceous formation. Such rocks are known far in the south, but only attain a great importance further to the north; they contain rich stores of mercury, as the mines of New Idria, New Almaden on the Clear lake, &c., bear witness.

In the south the Tertiary deposits predominate; towards the north they lose in importance, and the Cretaceous outcrop gains in extent. To the north of the Clear lake the former have nearly disappeared. The Cretaceous, except in a few localities, is very poor in organic remains, and chiefly composed of shales and sandstone; intercalations of hydraulic limestone increase its resemblance to the Cretaceous Flysch[1].

Gabb has divided the Cretaceous of California into four series: the *Téjon group* is the uppermost—in this region it is the only subdivision which includes beds of coal: the *Martinez group*, of no great extension and of doubtful independence: the *Chico group*—this is the most important of all; it extends as far as Oregon and Vancouver and appears to be the oldest member represented at the foot of the Sierra Nevada; one of its characteristic fossils is *Trigonia Evansi*; it is probably very nearly equivalent to the Dakota group and the Cenomanian, including perhaps higher stages: the lowest member is the *Shasta group*, which most likely includes subdivisions of different age, such as the Gault and Neocomian; it is known as far as Puget sound in the north and contains species of Ancyloceras, Crioceras, Helicancylus, Diptychoceras, and others. This is the oldest fossiliferous horizon in the Coast ranges, with the exception of a bed in the neighbourhood of the Clear lake containing *Aucella Piochi*, which is closely related to *Aucella Mosquensis* of the highest part of the Jurassic deposits of Russia[2].

Finally, recent volcanic formations are also present in these mountains. The most important band lies to the north of the bay of San Francisco, and runs from south to north past mount Saint Helena to the Clear lake.—

A description by Gabb affords us an opportunity of extending our comparative study to the peninsula of *lower California*. Gabb recognizes in this the undoubted continuation of the Coast ranges, and, indeed, not only are the rocks the same in both, but also the arrangement of the chains[3].

[1] Whitney, Geology of California, I, pp. 12, 101.

[2] W. M. Gabb, Palaeontology of California, 1869, II, Preface, pp. xii–xiv.

[3] Gabb, Notes on the Geology of Lower California, in Whitney, Geology of California, II, Coast Ranges, Append., pp. 137–148.

An uninterrupted band of granite extends from the mountains of San Gabriel, into the Coast ranges of upper California, through the counties of Los Angeles, San Bernardino, and San Diego to the western half of the peninsula, and appears to terminate to the north of the great bay of San Sebastiano Vizcaino. On the west side it is accompanied in places by older eruptive rocks, and bears isolated bosses and sheets of trachyte and basalt. To the east of this granite range, in the northern part of the peninsula, there emerges from beneath barren sheets of basalt a second granite range, which follows the east coast and extends still further to the south as far as the neighbourhood of Santa Gertrudis. Between these chains in the neighbourhood of Calamujuel, quartzite, mica-schist, talc-schist, and beds containing jasper occur, which are regarded as the metamorphic equivalents of an extensive sheet of unfossiliferous sandstone; this is the Mesa sandstone which corresponds to the Tertiary sandstone of upper California.

The mountains of Santa Clara, which extend from the bay of San Sebastian to that of Ballenas, probably form a third independent granite range.

Near San Ignacio stand some small ash cones of recent age, which are brought into connexion with the much higher but also volcanic mountains of the Cerro de las Virgenes by other recent volcanic deposits running right across the peninsula.

From this locality to the neighbourhood of La Paz the peninsula appears to possess a fairly regular structure. The Sierra Gigantea, about 3,000 feet high, extends close along the east coast, which for long intervals is bounded by extremely steep slopes, while the descent towards the Pacific Ocean is very gentle. The country is formed chiefly of the Mesa sandstone above mentioned; Gabb did not succeed in finding fossils in it. In the west the sandstone lies approximately horizontal and is broken up into Mesas, i.e. table-mountains; towards the east it rises up to the summit of the Sierra Gigantea, where the bedding is disturbed, and near Loreta the granite is visible beneath it. It contains numerous great blocks of an older eruptive rock, which do not seem to have been derived from the existing peninsula, but from somewhere in the east, or the region at present occupied by the gulf of California.

The Mesa sandstone extends to the south, until in the chain of the Cacachilas, which separate the bay of La Paz from the Californian gulf, granite again makes its appearance, associated with mica-schists; the latter rocks form the southernmost and loftiest part of the peninsula, where San Lazaro rises to a height of 5,000 feet.

In addition to the deposits already mentioned, very recent marine beds, described as post-Pliocene, are met with in several places up to a height of 400–500 feet above the existing coast.

Xánthus mentions the existence of an ancient and important quicksilver mine, near Marques, not far from La Paz [1].

The accounts at my disposal relating to the eastern side of the gulf of California are very incomplete. Nevertheless we may discover from them, especially from Weidner's observations on Sinaloa [2], that the mountains maintain a trend to the south-east throughout their course; and that in fact it is the Basin ranges, bent into this direction, which are continued as the chains of Mexico.

The boundary between the Coast ranges on the one hand and the Sierra Nevada, the Basin ranges, and Mexican chains on the other thus extends from the sources of the Sacramento through the longitudinal valley of California, past lake Tulare to the Téjon pass, to the mouth of the Colorado, and finally through the gulf of California.

This recalls the line of depression which runs from the desert of Atacama through the longitudinal valley of Chili to the bay of Corcovado. Indeed the correspondence between the Californian coast ranges and the littoral Cordilleras of South America both in structure and constitution is very remarkable. Here, as there, granitic chains form the basement: here also as there the Palaeozoic and the whole lower half of the Mesozoic series are absent, not a trace of them occurring above the granite.

Some remnants attributed to the Jurassic are known, but they are very few in number. With the exception of these, and so far as our knowledge extends at present, the stratified series from California down to cape Horn everywhere begins with the lower Cretaceous. Bands of serpentine are visible in many places. The occurrence of quicksilver in the Californian chains is repeated in Peru in the Cretaceous formation, though in this case it is found in the Sierra which succeeds the Coast Cordilleras on the east. Volcanos are superimposed on these chains in the south as in the north; and very often large masses of ancient eruptive rocks, which are perhaps Cretaceous, make their appearance.

Immense as is the distance over which these chains extend, yet they, and the Cordilleras of the Antilles with them, evidently belong to one and the same type of mountain structure, arising from a common cause, and recalling in many of its features the region of the Flysch in the mountains of Europe.

While the mountains of California are continued in this way to the south, they disappear towards the north beneath a flood of more recent lavas. The granite of the Sierra Nevada ends suddenly. Lassen's peak rises to a height of about 10,500 feet, and from this point the vast region of lava stretches to the north for a distance of more than 800 kilometers.

[1] J. Xánthus, Reise durch die kalifornische Halbinsel; Petermann's geogr. Mitth., 1861, pp. 133–143.

[2] F. G. Weidner, Der mexikanische Staat Sinaloa; op. cit., 1884, pp. 1–9, map.

It includes the whole of the Cascade range, covers very large surfaces in Oregon, Washington, and Idaho, and penetrates far into the surrounding states. Le Conte, who points out that the area of this volcanic region is equal to that of the whole of France, has shown that beneath the lava-streams, which are nearly 4,000 feet thick, very recent Tertiary deposits with remains of oaks and conifers occur, as may be seen on the banks of the Columbia river[1]. In the north of California, north-north-east of Lassen's peak, Mount Shasta attains a height of 14,400 feet and dominates for a great distance the surrounding country, the mean altitude of which is only about 3,000 feet: a long series of snow-covered volcanos follows, resting partly on the summit of the Cascade range, which is built up by their flows, partly to the west of this range, as for instance Mount Hood (11,225 feet) in Oregon, and mightiest of all, Mount Rainier (14,444 feet), in Washington territory. The latter bears a crater on its summit and glaciers occur on its slopes. Hague and Idding have investigated the rocks; they found basalt, hypersthene-andesite, hornblende-andesite, and in addition on Lassen's peak, dacite[2].

In certain places at the foot of the Cascade range smaller masses of granite and schist are exposed; these are the remains of the buried range submerged beneath floods of lava, which reappears to the north in British Columbia. The lavas appear to extend without any important interruption up to that part of the Snake river where the folded chains coming from Bear lake disappear beneath the basalts (Pl. VI).—

Towards the east, beyond the lava-sheets, lies so much unexplored country that it is impossible to make use of the remarkable descriptions by Hayden and Holmes of the volcanic region of the Yellowstone and bring them into connexion with the accounts we have of adjacent districts; we will therefore turn our attention to the regions further north.

*British Columbia.* According to the observations of G. M. Dawson, lake Winnipeg lies within the platform of flat-lying Silurian strata which were probably at one time continuous with the corresponding deposits of Hudson's bay. To the west of the lake lies a fairly broad zone of Devonian, which contains salt and petroleum, and is continued beyond the Athabasca; it lies almost horizontal and is overlaid on the west by the Cretaceous deposits of the plain, which begin west of the Winnipegosis in a well-marked scarp: this is a continuation of the scarp which has already been mentioned as occurring on the left shore of the lower Red river.

The Cretaceous formation spreads over the plain precisely as in the

[1] J. Le Conte, On the great Lava-Flood of the West and on the Structure and Age of the Cascade Mountains; Am. Journ. Sc., 1874, 3 ser., VII, pp. 167–180, 259–267.

[2] A. Hague and J. P. Iddings, Notes on the Volcanos of Northern California, Oregon, and Washington Territory; Am. Journ. Sc., 1883, 3 ser., XXVI, pp. 222–235.

south; after forming a gentle synclinal, it again becomes level, with a slight inclination to the west. About 15–30 kilometers from the foot of the Rocky mountains parallel disturbances begin to appear; even inverted folds occur, and on the border of the mountains, between latitude 49° and 50° N., the Cretaceous formation dips in a reversed direction towards the Rocky mountains. Dawson explains this by a great fault with a downthrow to the east which follows the foot of the mountains[1].

As the Laramie stage approaches the mountains, signs of the proximity of land become increasingly frequent; in its lower part it contains coal. Dawson suggests that the Rocky mountains themselves formed the coast-line. It will be recollected that similar theories have applied to regions more to the south, as far down as the north of Mexico.

Even much further north, in about latitude 55° 30′, where the Pine river, a southern tributary of the Peace river, has left the mountains, Dawson found similar conditions; the Laramie stage contains a good deal of sandstone and many pebbles, the Cretaceous beds are disturbed and sometimes even inverted within about 25 kilometers of the foot of the mountains. Here in the north, however, the exterior chain does not consist of Archaean and Palaeozoic rocks, but of Palaeozoic and the marine Trias with *Monotis subcircularis*[2].

The lofty ranges between this outer border of the Rocky mountains and the Pacific coast have been investigated by Hector, Selwyn, and Dawson, and though their researches are restricted to a few traverses, yet they have clearly shown that a fairly parallel strike to the north-west prevails throughout, and the structure is consequently much simpler than in the United States[3].

Dawson distinguishes four parallel chains in British Columbia. The first is formed by the *Rocky mountains*, in the north of which the Devonian beds again appear which occur to the east of the Mackenzie in an approximately horizontal position. The second chain is the *Gold range*; it is

[1] G. M. Dawson, Preliminary Report on the Geology of the Bow and Belly River Region, Geol. Surv. Can. Rep., 1880-1882 B, pp. 1-23, map; by the same, Descriptive Note on a General Section from the Laurentian Axis to the Rocky Mountains North of the 49th Parallel, Proc. and Trans. Roy. Soc., Canada, 1882-1883, I, sect. iv, 1882, pp. 39-44. For a line situated somewhat more to the north, see J. W. Dawson, Observations on the Geology of the Line of the Canadian Pacific Railway; Quart. Journ. Geol. Soc., 1884, XI, pp. 376-388.

[2] G. M. Dawson, Report on an Exploration from Port Simpson on the Pacific Coast to Edmonton on the Saskatchewan, Rep. Geol. Surv. Can., 1879-1880 B, p. 114; also Selwyn, Report on an Exploration of British Columbia, op. cit., 1875-1876, p. 81 et seq.

[3] J. Hector, On the Geology of the Country between Lake Superior and the Pacific Ocean (between the 48th and 54th Parallels of Latitude), Quart. Journ. Geol. Soc., 1861, XVII, pp. 388-445, map. Further numerous accounts by Richardson, Selwyn, J. W. Dawson, and G. M. Dawson in the Rep. Geol. Surv. Can., and Dawson, Sketch of the Geology of British Columbia, Geol. Mag., 1881, 2 ser., VIII, pp. 156-162 and 214-227.

bounded on the west by a broad plateau covered with recent lavas and fresh-water deposits: beyond this plateau rises the *Coast or Cascade range*, which is here no longer buried beneath the lavas; it must of course not be confused with the Coast ranges of California: the fourth chain is the *Vancouver range*; it rises from the sea and the Queen Charlotte islands form part of it.

The Rocky mountains are expressly declared by the same observer to be the continuation of those Palaeozoic platforms which lie beneath the great eastern plains. The Mesozoic deposits certainly exhibit important modifications as to distribution. In the south the red sandstone with gypsum, which represents the Trias, extends from the plains into the Rocky mountains, and may even be traced as far as the Wahsatch; then the Trias disappears and is wanting over a fairly broad strip of country, but it reappears in the western Basin ranges as a marine deposit with Meekoceras, *Monotis subcircularis*, and other fossils. In the north, however, the marine type of Trias spreads across the whole breadth of the range; deposits of this marine Trias with *Monotis subcircularis* crop out in the west on Moresby island (Queen Charlotte archipelago, lat. 53° N.), from beneath Cretaceous beds of the Californian type; and on the east side of the range, on the Peace river and Pine river, the same marine deposits are found in contact with Cretaceous beds of the eastern type, resembling those of Dakota and of Colorado [1].

The Aucella-beds which have already been mentioned as occurring in the Coast ranges of California again appear in several localities, and particularly on Vancouver island. Whiteaves lays stress on the identity of the Californian *Aucella Piochi* with *Aucella Mosquensis*, and assigns the whole series of beds to the lower Cretaceous; I agree with Neumayr in regarding these beds as the deposits of a boreal sea, which at the close of the Jurassic period penetrated to the south as far as California [2].

Alaska and the Aleutian islands will be discussed in connexion with eastern Asia. It would appear that no prolongation of the Coast Cordilleras can be traced into British Columbia.

*Summary.* Since the appearance of their classic work on the Geology

[1] J. Richardson, Report on Vancouver and Queen Charlotte Islands, Rep. Geol. Surv. Can., 1872–1873, pp. 38–101, map, and 1874–1875, pp. 78–91; G. M. Dawson, Report on Queen Charlotte Islands, op. cit., 1878–1879 B, pp. 1–275, geological map; and by the same, Note on the Triassic of the Rocky Mountains and British Columbia, Proc. and Trans. Roy. Soc. Canada, 1882–1883, I, sect. iv, pp. 143–145; and Note on the Geology of the Peace River Region, Am. Journ. Sc., 1881, 3 ser., XXI, p. 891.

[2] J. F. Whiteaves, On the Lower Cretaceous Rocks of British Columbia, Trans. Proc. Roy. Soc. Can., 1882–1883, I, sect. iv, p. 85; M. Neumayr, Ueber klimatische Zonen während der Jura- und Kreidezeit, Denkschr. Akad. Wiss. Wien, 1883, XLVII, p. 303. Meek was also inclined to identify *Lima Erringtoni* of the gold-bearing slates of California with *Auc. Mosquensis.*

of Pennsylvania by the brothers Rogers, and since we have become familiar with the structural plan of eastern America, which has been established by a long series of investigations mutually supplementing each other, attention has been turned to the west, and in this region the united and zealous researches of a galaxy of distinguished observers have successfully revealed the fundamental features of the structure of one of the most remarkable and extensive mountain assemblages in the world. We who are thus enabled to obtain a comprehensive view of these features cannot refrain from an expression of gratitude to those who have paid for this valuable result with the labour of their best years.

From Nova Scotia and even from Newfoundland great folds extend through the east of the continent as far south as Alabama; they are not quite parallel, and they have come into existence at different times, but they all follow nearly the same direction to the south-west, which is that of the existing coast, and they reveal a long-continued or frequently repeated tangential movement which is directed to the west and north-west, i.e. towards the interior of the continent. The Atlantic Ocean thus lies on the back or inner side of these folds.

Further to the west these folds flatten out; finally a great Cenomanian transgression makes its appearance, traces of which are not wanting also on the Atlantic coast, as in New Jersey.

The deposits of the middle and upper Cretaceous form the basement of the Llano Estacado and of the prairies extending from Texas far towards the north; they penetrate into the interior of the mountains, and in the south they probably stretch uninterruptedly to the Pacific coast. The central plain of the continent is formed by these deposits. The series closes with a great brackish and fresh-water formation deposited in the inland lake of Laramie, and extending from the banks of the Peace river to those of the Rio Grande del Norte. The Mesozoic deposits of the plains, horizontal over great areas, are suddenly tilted up close to the foot of the first chains of the Rocky mountains, such as the Front range in Colorado, as though they had been dragged along a great fault. Towards the south in New Mexico they are to some extent inverted; the movements attain their greatest intensity in the north on the upper tributaries of the Saskatchewan and the Athabasca, where a somewhat broader zone of repeated dislocations is present.

The Rocky mountains, from their commencement near Galistea in New Mexico up to the mass of the Téton, that is from 35° 30′ to 43° 30′ approximately, are formed of mighty ranges which rise one behind the other, along a straight line running with the meridian; each range shows a tendency to diverge towards the north-west, so that even the broad ridge of the Uinta which trends to the west takes part in this peculiar virgation. The summits of most of these ranges are too broad to be regarded as true

anticlinals, and the simple upturning of the edges of the Mesozoic sediments around the larger masses is not peculiar to them, but also occurs around the smaller cores, which protrude like pegs. For this reason the country surrounding the mountains, and particularly the Colorado plateau, has here been regarded as let down, and the bordering great flexures, as the peripheral flexures of the sunken area. The mountains thus present the characters of horsts, and even the high plateaux of Utah must be regarded as the result of unequal subsidence. It is into this region that the Cañon of Colorado is sunk.

The sediments of inland lakes representing the various subdivisions of the Tertiary formation are spread out over the sunken area of the Colorado plateau, to the south of the Uinta and over the plateau of the Green river, north of the Uinta.

Along the Wahsatch and beyond the high table-lands of Utah begins the region of folds broken down by subsidence, the Basin ranges; they are continued both to the north and south. In this region only parallel chains appear to be present, without any intercalation of other ranges to recall the virgation of the Rocky mountains or the plateau of the Green river and of the Colorado.

The Sierra Nevada, formed of gneiss and Mesozoic slate, has been represented as a folded system, inverted to the west, similar to that of the Finster-Aarhorn: at its western foot the middle Cretaceous lies horizontally.

Oregon and Washington are covered by the great lava-flood: it is only in British Columbia that the rocks of the Cascade range reappear from beneath the flows to form continuous chains, while more to the south only great volcanos surmount this range. In front of the Cascade range fragments of another chain survive in Vancouver island and the Queen Charlotte archipelago.

In California the Cretaceous zone at the foot of the Sierra is followed by the great longitudinal valley, which is continued beyond the Téjon pass into the gulf of California. All that lies outside this line of depression, the Californian Coast ranges and the peninsula of lower California, presents the same peculiar constitution as the Coast Cordilleras of South America and the Cordillera of the Antilles. From the north of California to cape Horn, through nearly 95 degrees of latitude, the Pacific coast is bordered by a series of short chains which replace one another laterally: throughout their whole course they consist of rocks of Archaean stamp, with many ancient eruptive rocks, and also of sediments. The most ancient fossils these have hitherto afforded indicate traces of Lias in Bogota, and in California traces of the highest horizon of the boreal Jurassic; everywhere else they point exclusively to the Cretaceous and Tertiary periods.

Darwin in the extreme south and Whitney in the north have expressed their belief in the recent age of the granites of these chains.

Many indications exist to suggest that changes are still taking place in our own time in the ranges of western America. A few years ago a great earthquake was observed along one of the principal faults. Gilbert has traced the disturbances of the terraces on Lake Bonneville: craters lie between them. Other craters occur on the Esplanade, that great step in the Grand Cañon of Colorado, and their lavas have flowed into the lower ravine, which is certainly of no great age. In the Sevier desert the craters and lavas of the Fillmore group look so fresh that Gilbert remarks there is here no more reason to suppose that the basaltic epoch is concluded than that it has just begun [1].

[1] Gilbert in Wheeler, Surv. 100th Merid., III, pp. 136, 141.

# CHAPTER XII

## THE CONTINENTS

Old and New World. These expressions untenable. Age of the continents. America. Separation of Indo-Africa and Eurasia. Folding of Eurasia. The Han-hai and the depression of Turkestan. The Mediterranean seas. The Indian Ocean. The great units. Multiformity of the mountains. Collapse of the lithosphere.

THE preceding chapters contain a description of a number of the chief mountain chains of the earth, the largest table-lands, and the Mediterranean seas. The treatment has differed according to the importance of the subject and the existing state of our knowledge. Most of the outlines we have sketched are conterminous; but in America, owing to the inadequacy of existing descriptions, it was not found possible to trace the Mexican chains quite to their southern extremity, and consequently there was no opportunity of referring to the transverse series of volcanos in Mexico. The Arctic lands, the north-west of Europe, the table-land of north China, the whole of the eastern coast of Asia, and finally Australia with the Pacific islands have not yet been discussed. These omissions will be remedied in later chapters, and the regions forming the framework as it were of the two great oceans will be studied in a full and comprehensive manner. Apart, however, from any intentional restriction of the subject, there is no lack of involuntary defects, due to the fact that this method of description, which aims at comparison, suffers from an almost entire absence of models; it therefore exhibits all the imperfections of a first attempt.

The treatise by Alexander von Humboldt, 'Geognostischer Versuch über die Lagerung der Gebirgsarten in beiden Erdhälften' (Geognostic Essay on the Position and Arrangement of the Rocks in both Hemispheres), appeared in 1823, and is now only of interest as a monument to the intellectual greatness of its author. Even Ami Boué's geological map of the earth published in 1845 has become, owing to the rapid progress of research, only of historic value; and J. Marcou's text to the second edition of this map which appeared in 1875, though an invaluable summary, is devoted like Boué's work rather to tracing the distribution of the various formations over the earth's surface than to an investigation of the structure of the mountains and ocean basins.

The object of the present work is approached much more nearly by the attempts, unfortunately still rare, to compare different mountain regions together. As examples I may mention the comparison of the Alps and the

Himálaya by Medlicott in 1868, and the comparison of the Pyrenees, the Central Plateau, and the Vosges by Bleicher in 1870: an essay which at once and in the most brilliant manner showed the value of the comparative method, since it led the author to perceive that the Vosges must be regarded as a horst[1]. A general comparative orography, drawn from the existing store of observations, has not yet been created, and he who endeavours step by step to organize the elements of such a synthesis must be content if he finds that the structure he has raised is open to completion and correction, the means for which is provided year by year, nay, almost day by day, by the zeal for this branch of study newly awakened in all parts of the world.

Notwithstanding much incompleteness, a certain number of general results stand out so clearly from the preceding chapters that we will here give a preliminary summary, chiefly with a view to facilitate in some degree the synthetic task reserved for later chapters. I have already described the spiral arrangement of the several branches of the Alpine system, and then, by tracing the virgation of the Thian-shan and the great Roumanian curvature, have shown how to distinguish and arrange the parts of this spiral; I will now briefly draw attention to some general features on the face of the earth, leaving the exposition of their deeper significance to a later page.

Even as we cannot form a judgement as to the existing condition of a State unless we know how it has been brought about, so we are just as little able to arrive at a true view concerning that fragment of the earth's crust on which the State is situated without a knowledge of the events through which it has passed, and of the processes by which it has been built up. In human affairs as in the physical world the present is only a transverse section; we cannot see the future which lies beyond, but we may gain instruction from the past. Thus the history of the earth is of fundamental importance in the description of the earth.

When we attempt to make use of the knowledge gained in a study of the past history of the earth in order to arrive at a generalized picture of its surface, we find ourselves at the very first step brought face to face with a fact which shows how little this method has hitherto been employed. Even to-day we speak of an *Old World* and a *New*, and the 'Old World' is the only expression in general use to designate the mass of Asia, Africa, and Europe. The incompatibility of this traditional expression with the results of modern science has been recognized by American investigators, and in works on zoogeography they have introduced in its place the name *Eurasia*.

[1] H. B. Medlicott, The Alps and the Himálayas, a Geological Comparison, Quart. Journ. Geol. Soc., 1868, XXIV, pp. 34–52; G. Bleicher, Essai de géologie comparée des Pyrénées, du Plateau central et des Vosges, Thèse présentée à la Faculté de Strasbourg, 8vo, Colmar, 1870.

As to the criteria by which the age of a continent should be judged, it is far from easy to decide, since in most cases parts of different age contribute to its formation; and, what is more, by 'age' we sometimes understand a sharply defined date for the long-continued processes of formation, sometimes the date of the last emergence of the continent from the ocean. We shall probably approach most nearly to the general use of the word, if we take it to mean the time when the great depressions of the continent were finally abandoned by the sea.

*North America* was covered by the sea of the middle and upper Cretaceous from the gulf of Mexico to the Mackenzie, and perhaps as far as the Arctic Ocean, over all the region which lies between the mountain ranges of the east and west; some of these ranges even being themselves submerged. The sea then disappeared; an extremely large brackish and fresh-water inland sea, lake Laramie, extended over the interior of the existing continent from lat. 33° almost to lat. 60° N. Such was the condition of this continent during the interval between the close of the Cretaceous and the beginning of the Tertiary; the deposition of extensive fresh-water beds then commenced and continued throughout the whole of the Tertiary period; since that time the ocean has never again advanced over the land, and White has shown that the characteristic elements of the existing fauna of the Mississippi, the Ganoids and the Unios, are directly descended from those which have left their remains in the Laramie deposits [1]. Looked at from this standpoint North America must be regarded as having been in existence since the time of lake Laramie; it is consequently a fairly ancient continent.

The most recent traces of the sea in the interior of *South America* are the brackish water deposits of Pebas on the Marañon, which Brown has traced from the east of Peru down the river to San Paolo [2], the most easterly point at which they occur, though still more than 2,000 kilometers from the Atlantic coast. The fall of the Amazon is, however, very gentle; and our knowledge is incomplete, since exploration has not made so much progress in this country as in North America. The deposits of Pebas are believed to be middle Tertiary. From the south-east also the Tertiary deposits advance far into the interior of the land.

If we attempt to make similar comparisons with regard to the united mass of Asia, Africa, and Europe, it at once becomes evident that heterogeneous regions—the limits of which do not coincide with the recognized

[1] C. A. White, A Review of the Non-Marine Fossil Mollusca of North America, U. S. Geol. Surv., 1881-1882, in particular p. 73 et seq.; by the same, Certain Phases in the Geological History of the North American Continent: Presidential Address delivered at the Fourth Anniversary Meeting of the Biol. Soc. of Washington, Jan. 25, 1884, Proc. Biol. Soc., II, p. 24, and in other places.

[2] C. Barrington Brown, On the Tertiary Deposits on the Solomões and Javary Rivers; Quart. Journ. Geol. Soc., 1879, XXXV, pp. 76-88.

boundaries of these subdivisions—have here been welded together to form one great continent.

The first region comprises the southern and a great deal of the more central part of Africa, then Madagascar and the Indian peninsula. The lofty table-lands of this region have never, so far as we know, been covered by the sea since primitive times, or the end of the Carboniferous period; it is only at the foot of the table-lands that marine sediments have been deposited, which followed the encroachment of the Indian Ocean, as this was formed by subsidence within the tabular mass. We call this mass Gondwána-Land, after the ancient Gondwána flora which is common to all its parts; it corresponds to a large extent with the Lemuria of zoologists; judged from the standpoint we took before, this country is incomparably older than North America.

Gondwána-Land is followed on the north by other plateaux; these, however, were submerged during the Cretaceous, and to some extent even during a part of the Tertiary period; they include the Sahara, with Egypt, Syria, and Arabia.

This desert region, together with Gondwána-Land, forms one great unit, bound together in all its parts by common characters; this is *Indo-Africa*, distinguished above all by the absence of folding since the conclusion of the Palaeozoic aera.

That which remains of the collected mass of the three continents after the abstraction of Indo-Africa may be called *Eurasia*.

*The whole southern border of Eurasia advances in a series of great folds towards Indo-Africa*; these folds lie side by side in closely syntactic arcs, and for long distances they are overthrust to the south against the Indo-African table-land.

There thus arises a very sharply marked line of separation. This runs in the north-west of Africa from the Wady Draa to the east-north-east; passing somewhat to the north of the Shotts and the Syrtis Minor (gulf of Gabes) it extends between Malta and Sicily towards the straits of Otranto, then returns upon itself outside the Ionian islands, and next describes an arc to the south of Crete and Cyprus into the region somewhat to the south of the mouth of the Orontes; it continues thence along the same arc in the direction of Djarbekr, then curves round to the south-east and follows the foot of the mountains on the east of the Tigris, is continued through the Persian gulf and to the south of the coast of Makrán to the mouths of the Indus; thence it runs to the north nearly following this river to above Dera Ismail Khan, then in a sudden contortion curves through Kalabágh to Jalalpúr on the Jehlam, follows the foot of the Himálaya in a broad arc into the valley of the Brahmaputra in Assam, then bends sharply round and proceeds along the outer border of the chains of Arakan to cape Negraïs, passes on the west outside the Andaman and Nicobar islands, and joins

the zone of Tertiary land which appears as a chain of little islands to the west of Sumatra; finally it is continued still further to the south of Java.

The whole southern part of Eurasia, so far as we have hitherto considered it, is a folded region. From the Himálaya to the mountains of Mongolia the assembled folds, always pushed towards the south, extend over a breadth of 22° of latitude, and they run under manifold modifications towards the west, appearing in the south as syntactic arcs, further to the north as rod-like diverging branches. As they reach Europe, the part which extends furthest to the west, that is the branch which proceeds from the Paropamisus and is continued past Krasnovodsk and the Caucasus, undergoes a complete reversal in the direction of the folding, and passing through a mighty torsion in the Roumanian arc, is driven in the Carpathians, and in the main body of the Alps towards the north. This circumstance distinctly indicates that the folding of the uppermost part of the earth's mass is, under certain conditions, only the expression of a forced adaptation. To the north of the great folded chains lies the Russian Platform, and further on, beyond these, the numerous horsts and fragments of plateaux appear which are characteristic of central and western Europe.

A great part of this folding is of recent age, or has been continued into very recent times; it is not certain that the movement has ended. The first member of the Mediterranean deposits surrounds the whole principal border of the Alps and is folded into the northern side; the saliferous Schlier, which is somewhat younger still, embraces the Carpathian arc in like manner. Very recent fresh-water deposits take part in the outer folded ranges of the Hindu Kush and the Himálaya. It is extremely likely that within the region of the existing folded ranges an uninterrupted sheet of water at one time extended from the Han-hai, the 'dry sea' of the Chinese, to the plain of Turkestan; and the very considerable heights at which younger Tertiary deposits have been observed on the chains of the Thian-shan by Russian geologists show, as Muschketoff justly remarks, that this connexion was effected not only across the Dsungaric passes, but also over a good part of that region which is at present occupied by the great ranges. The first extension of the Mediterranean appears to have been restricted by the advance of the Swiss Alps towards the north-west, which destroyed the connexion between the seas occupying the lower valley of the Rhone and the middle valley of the Danube; a similar separation may also have been caused by the movements of the central parts of the Thian-shan.

As a consequence of these events Eurasia has acquired a remarkable diversity of structure. In North America the homogeneous nature of the region, and the continuity of the fresh-water faunas from that of the Laramie to that of the existing Mississippi, have led to a clear and simple result as regards the emergence of this continent from the sea and the unification of its parts. In lake Tanganyika we meet with a highly remarkable molluscan

fauna, distinguished by many features recalling marine forms; this, as White and Tausch have shown, recalls in many of its species the fauna of Laramie, and its great antiquity is beyond all doubt [1]. The African rivers are distinguished by a great number of ancient forms of life; we have already mentioned their fragmentary distribution and the occurrence at the present day of fishes from the Nile in lake Tiberias and of the Nile crocodile in Syria. Great fresh-water lakes have existed in several parts of Eurasia during late Tertiary times, as, for instance, in the region of the Aegean sea, in Slavonia, and Croatia. Their fauna resembles in many respects that of the existing Mississippi, and Fuchs has shown from the collections of Anderson and Heude [2], as Neumayr also from the mollusca brought home by Széchény and Lóczi, that the same types have maintained their existence in Nanking and Yünnan [3] down to the present day. In the middle of Eurasia the withdrawal of the waters of the ocean has led to the formation of a number of inland seas, the largest of which is the Caspian, the direct descendant of the ancient continental sea. Here lie the stunted and transformed remains of the ancient faunas, first of the impoverished Sarmatian, then of the lacustrine fauna; but since this restriction of the waters occurred, the Aegean sea and the existing Pontus have come into existence quite independently of the Caspian, as a consequence of collapse; thus it comes about that so many east European rivers which are at present completely separated from one another contain so large a number of corresponding species of animals.

This is the fundamental difference between the ancient Caspian and the more recent Pontus.

The collapse of the Aegean and the Pontus is but one episode in the series of events which have given to the Mediterranean its existing form. We are now in a position to distinguish the following parts in the Mediterranean region:—

The first is the western Mediterranean extending from Gibraltar to the sea between Sicily and Malta. This is surrounded by the Apennines, the mountains of North Africa, and the Betic Cordillera; it lies completely within the great curve formed by these mountains, or enters its transverse fractures, as in the straits of Gibraltar and between Dak'hela and Sicily.

The second part corresponds to the Adriatic sea. It lies on the syntactic union of the Apennines and the Dinaric mountains, or rather

[1] L. Tausch, Ueber einige Conchylien aus dem Tanganyikasee und deren fossile Verwandte, Sitzungsber. Akad. Wiss. Wien, 1884, XC, and already indicated in White, Proc. U. S. Nat. Mus., 1883, p. 98.

[2] T. Fuchs, Ueber die lebenden Analoga der jungtertiären Paludinenschichten und der Melanopsis-Mergel S. O. Europa's; Verhandl. geol. Reichsanst., 1879, pp. 297-300.

[3] Neumayr, Ueber einige Süsswasserconchylien aus China; Neues Jahrb. f. Min., 1883, 6, pp. 21-26.

on the in-sunken western border of the Dinaric chains, and its marginal fractures extend into the Alps as far as Meran and Bruneck. It resembles in many respects the valley of the Brahmaputra in Assam. In that case the Shillong plateau, a part of the table-land, is wedged in between the foot of the Himálaya and the Burmese folds; and it is an open question whether this analogy might not afford a better interpretation of the Apulian table-land.

The third part is bounded by the fragments of the Dinaro-Tauric arc, in particular by Crete and Cyprus. It includes the Aegean sea and the Pontus; the marginal zone bordering the south coast of Asia Minor holds a position similar to that of the gulf of Pegu.

All these three parts fall within Eurasia; only the fourth part is to be assigned to Indo-Africa. This is a sunken foreland let down in horizontal tabular masses; it begins in the great Shotts, reaches the sea in the gulf of Gabes, and extends to the meridional faults of Syria. Of all the numerous islands of the Mediterranean only Malta and Gozzo are to be assigned to Indo-Africa; on the other hand the mountain range of the north-west of Africa belongs to Eurasia.

The *American Mediterranean* may be similarly resolved into several parts. The Cordillera of the Antilles resembles in plan the arc-shaped border of the western Mediterranean with its downthrown inner side, and the Caribbean sea occupies a position similar to that of the western Mediterranean; both also are beset with volcanos on their margin. The gulf of Mexico, on the other hand, corresponds to the sunken tables of the foreland, that is to the south-east part of the Mediterranean. The Bahamas and Florida repeat on a larger scale the horizontal stratification of Malta; and volcanos are absent.

These differences also to no small degree find their expression in morphological characters, and we learn to distinguish sunken areas in folded country from subsided table-land. The outlines of Cyprus or Haiti are examples of the first case; the outlines of broken table-lands are, if the expression may be permitted, amorphous, or they take the form of straight lines as on the Syrian coast.

Furnished with these results obtained in the Mediterranean seas let us now turn to an ocean, and first of all the *Indian Ocean*. Here only the gulf of Pegu and the Sunda sea lie within the folds of Eurasia. We may regard the gulf of Persia as a zone of sunken foreland; the Red sea resembles a great trough-subsidence in the table-land; all the rest of the vast surface from the Cape to the coast of Arakan is to be regarded—judging from the structure of the coasts and islands and the succession of their strata—as subsided table-land. This is the in-sunken part of Indo-Africa.

The preceding remarks furnish us with a basis for the consideration of

that fundamental difference which exists between the outlines of the Pacific and of the Atlantic Oceans. Several portions of these coasts have already been discussed in the foregoing sections: we have pointed out the remarkable similarity both in structure and stratified sequence which is presented by all the Coast Cordilleras, from Staten island and cape Horn onwards to the north, through Patagonia, Chili, Peru, and the tropical region of South America, and again through lower and upper California, i.e. through more than a quarter of the earth's circumference. After having described the manner in which the syntactic arcs of the great chains push forward against the north of the Indian peninsula, we observed that a similar advance of syntactic arcs takes place towards the north of the Pacific Ocean, and that a special tectonic homology exists between that fragment of ancient table-land and this part of the ocean. In the Atlantic Ocean, on the other hand, we found ourselves, along the east coast of North America, on the inner side of a folded system, the Appalachians, moved towards the interior of the continent. A comparison of the contours of each ocean as a whole will be the task of a special chapter.—

We are now able to distinguish among the continents which rise above these oceans several units.

The first of these is *Indo-Africa*, the greatest table-land of the earth, limited on its northern border, from the point where the Wady Draa discharges into the Atlantic Ocean to the mouth of the Brahmaputra, by the folds of Eurasia advancing to the south, but elsewhere, as far as it is known to us, surrounded solely by faults and divided in two by the Indian Ocean.

The second unit is *South America*, a shield, as it were, girdled on three sides by mountain ramparts; broken off without perceptible trend-lines on the east and north-east, and with open virgation of the branches of the mountains to the south-east between Cape Horn and Cabo Corrientes.

The Cordillera of the Antilles shows a closer affinity to South than to North America.

The third unit is *North America*; so far as folding is known in this continent it appears to be everywhere directed to the west, with a few exceptions caused perhaps by local overthrusting on to the subsidence at the outer border of the Rocky mountains; this westerly movement began in extremely ancient times, and manifests itself from the Atlantic coast to the Pacific, from the Appalachians to the Sierra Nevada and the Coast chains. Towards the north, however, a very extensive 'plate' without folding appears, which stretches nearly to the Arctic archipelago, and which still remains to be discussed.

Least obvious as an organic whole, notwithstanding the extraordinary magnitude of the folded area on its southern border, is the unit of Eurasia. Here we are in presence of much greater complexity and diversity; the

description of its various parts is not yet advanced far enough to enable us to bring it into comparison with the other continents. For the same reason I must provisionally pass over Australia in silence.—

The movements of the earth's crust have given rise to a great variety of structural features. We see great horizontally stratified platforms, such as those of Russia, Brazil, and the Sahara; lofty ancient table-lands, as on both sides of the Indian Ocean, bounded by abrupt scarps like the Quathlamba in Natal and the Sahyádri in India; and isolated table mountains like that at the cape of Good Hope, and Roraima in the south of Guiana. There are the horsts which stand out in relief owing to the subsidence of the surrounding country, such, for instance, as the Morvan, Vosges, Schwarzwald, Frankenwald, the granite mass of Madagascar, and probably also a large part of the Rocky mountains with the Uinta; beside the horsts we see the sunken areas, such as that of Franconia and Swabia, and the plateaux of Colorado. Troughs are let down between parallel faults, such as the Rhine valley near Strassburg, the Dead sea, and probably also Tanganyika and the entire Red sea.—In ancient primitive formations, completely levelled down, the traces of great folded ranges are in many places visible, the outward form of which has been entirely lost, as, for instance, in the region of the great American lakes as far as lake Winnipeg, and in the south part of the Russian plain. Other primitive folded ranges, still preserving in a few fragments their original form, are revealed by the destruction of the sediments which had buried them—such are the Arvali mountains in India and the Lange Berg on the eastern border of the Kalahari desert; so too the Mugodjars in south Russia have been washed out of the Cretaceous marl of the Ust-Urt which once covered them. We see great folded chains merge with gradually flattening undulations into the similar foreland, where they form secondary folds, or 'parmas'—this is the case in the Urals and the Appalachians; then again others which with numerous more or less parallel arc-shaped folds, like the surface of troubled water, rise up within a second folded region, moved in the same direction—such are the long and mighty folded ranges of the Thian-shan. Others present overfolding and overthrusting and are checked by an alien foreland—such are the Himálaya and the Alps; and between the points of obstruction mountains appear, not unlike a parma, as for example the Jura. There are chains which have been pushed onwards over their foreland, such as the Carpathians; many others of which the foreland is covered by the sea, as the Andes, and still others which advance into the sea, such as Vancouver and the Queen Charlotte archipelago. Some fragments of folded ranges have been completely crumpled up and broken along the strike by the lateral pressure of other folds, as in the step-like Salt range, with its overthrust segment, the Sheich Budin; others have been completely overwhelmed by transverse folds, like the Sudetes by the

Carpathians, and some have been twisted in the strike itself, like the Roumanian arc which runs from the Balkans to the Carpathians. In the Himálaya the direction of the folding along the Brahmâputra is directly opposed to that of the Burmese chains, which lie on the other side of the river, and the Harz has experienced two different successive movements of folding. Folded ranges may be seen bearing volcanos on their crest, the Albourz, Caucasus, and the South American Andes, for example; in some great arc-shaped folded ranges the backland has completely foundered, leaving behind a range much reduced in breadth on the inner side, and sometimes also interrupted, as in the Carpathians, the border of the western Mediterranean, the Cordillera of the Antilles, and the chain of Arakan with the Andaman and Nicobar islands. In this case the volcanos stand on the inner side. This is the situation of the Hungarian trachytes, the volcanic series of Italy, the volcanos of the south coast of Spain, of the Lesser Antilles, and of the volcanic series which extends from the Puppádoung on the Irawadi to Barren island. Other folded ranges are cut through by rectilinear fractures, hacked to pieces, sunk down in strips, and surrounded by recent lavas, so that it is not the course of the folds, but that of the faults and volcanic flows which determines their outlines, as in the Basin ranges; the fractures may also cut across the folds at right angles, so that the outlines follow a direction transverse to that of the folding, as in the east of Thessaly and in the island of Euboea, and under another form also in Guatemala and the Honduras; others again have sunk down along arc-shaped fractures lying in the strike, and are also in great part buried beneath ashes and lavas, as is the case with the Iranian-Tauric syntaxis of upper Armenia; in others only the volcanic cones which stand on strike faults are visible, as in Java, and here we seek laboriously before we find even slight traces of the mountain basement. Of other chains nothing but a fragment is still to be seen, as in the Crimea. There are important mountain masses, such as the Spanish peaks in front of the Rocky mountains, and the Henry mountains on the western border of the Colorado plateaux, which are only lenticular intrusions of volcanic rocks, and many similarly disposed granitic masses perhaps only represent the filling in of cavities which were produced by a splitting of the crust under tangential pressure.

Many classifications might be proposed, but for the development of the argument it is only necessary to distinguish four principal groups; these are the table-lands, the horsts, the folds, and the volcanic mountains. This distinction will be of importance when we attempt to discover the nature of oceanic transgressions.—

The great volcanic cones, Chimborazo, mount Rainier, Aetna, the lava-fields of the Deccan or those of Oregon and Washington, which cover many hundreds of square miles, tremendous eruptions, such as that of

Krakatoa, causing oscillations of the whole atmospheric envelope of the planet, recorded by the self-registering barometers all around the globe, are only secondary manifestations of those great processes to which the earth owes its form. They are indications of the temporary opening of little joints, nothing more.

The deluges, in which mountains of water arise and pour in a devastating flood over the land, are also merely secondary phenomena. The Anunnaki, as the ancient Deluge story calls them, the powers of the deep, have not retired to rest. A quivering of the earth's mass on the Chilian coast causes the whole Pacific Ocean to oscillate in its bed; its waves break on the Marquesas, Apia, Honolulu, sweep over the flat coral islands, and overflow its shores from Japan to New Zealand and Australia.

The stresses which result from the contraction of the outer part of the body of the earth are transformed, as we have said, into tangential folding and vertical subsidence. By the tangential movement those long folded ranges are produced which traverse the continents from end to end; by this the greatest mountains of the earth, Gaurisánkar (Mount Everest), the unnamed summit of the Mustagh, $K_2$, and all the giants of the great inner Asiatic ranges have been piled up; by this Jurassic limestone and gneiss have been kneaded together on the north side of the Finster-Aarhorn, and the gneiss has been carried over the folded Jurassic on to the summit of the Jungfrau. In very many cases this movement may have been preceded by subsidence of the foreland, by which the tangential movement was as it were *compensated*, so that the folding or overthrusting force became free, as in the Belgian coal-fields. The process is less clear when the folding affects a homogeneous foreland, and folds, or great parmas, are formed in front, such, for instance, as the Timan mountains in front of the Urals and the Cincinnati uplift in front of the Appalachians. But the frequent checking of the folds by exterior obstacles, the complete overfolding and reversal of the beds in the face of the obstructing masses, the mutual crowding and crowding out which may be seen in certain syntaxes of mountains, the opposition in the direction of the folding along the Brahmaputra, and the torsion in the strike along the lower Danube clearly indicate that in spite of the extremely great length of the folded ranges they have been obliged in their local development, and especially on their outer border, to accommodate themselves to pre-existing conditions.

A great number of regions, such as Indo-Africa, have experienced no kind of folding movement for a long time; the part they play is to check the folds or to subside in front of them. Movement in the second direction, i.e. subsidence or collapse, has on the contrary left its traces everywhere. Sometimes it produces great troughs in the midst of the table-lands, sometimes subsidence of plateaux along peripheral lines, at others caldron-shaped in-sinkings on the inner border of folded mountains, and at others

again the subsidence of folded mountains along longitudinal or transverse fractures. The diversity in character of the effects produced by downward movement is extraordinary, and their magnitude extremely great. It is to subsidence and collapse that the Mediterranean seas and the largest oceans owe their origin and enlargement.

The breaking up of the terrestrial globe, this it is we witness. It doubtless began a long time ago, and the brevity of human life enables us to contemplate it without dismay. It is not only in the great mountain ranges that the traces of this process are found. Great segments of the earth's crust have sunk hundreds, in some cases even thousands, of feet deep, and not the slightest inequality of the surface remains to indicate the fracture; the different nature of the rocks and the discoveries made in mining alone reveal its presence. Time has levelled all. In Bohemia, in the Palatinate, in Belgium, in Pennsylvania, in many other places as well, the plough quietly traces its furrows over the mightiest fractures.

If the tangential stresses in the outer crust of the earth completely balanced each other, and if the crust could sustain itself like a free arch, independent of all the processes which affect the interior, then neither collapse nor folding would take place; and the surface of the earth would probably present the form of a fairly regular spheroid, everywhere covered by a continuous ocean. It is the subsidences which have collected together the waters in the deep oceans; thus alone have the continents arisen, and beings which breathe by means of lungs become possible.

THE END OF VOL. I

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